

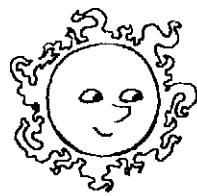
STORY OF ASTRONOMY

Wrong!
You guys have got it
ALL WRONG!



Written and Illustrated by

Uday Patil



Story of Astronomy
Written and illustrated by Uday Patil

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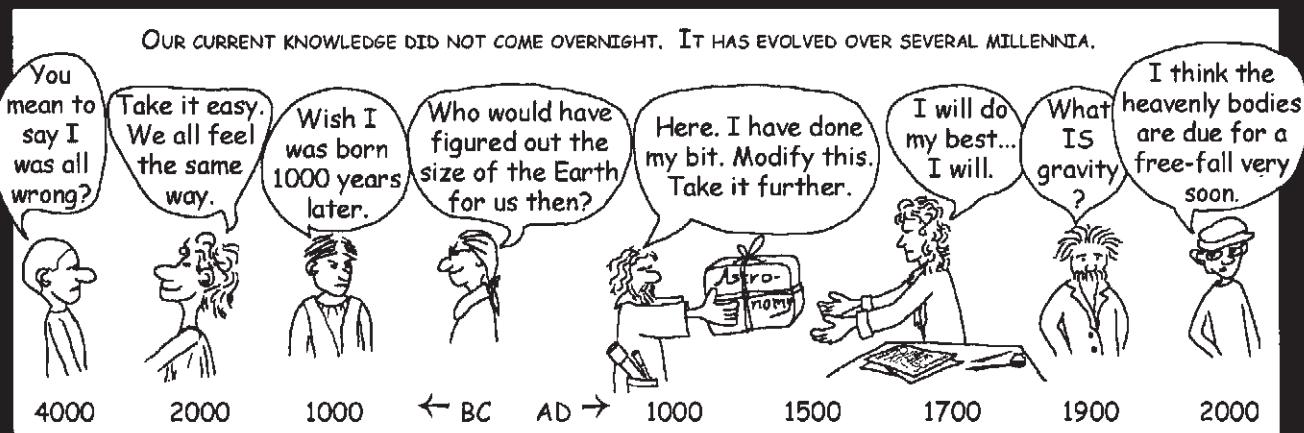
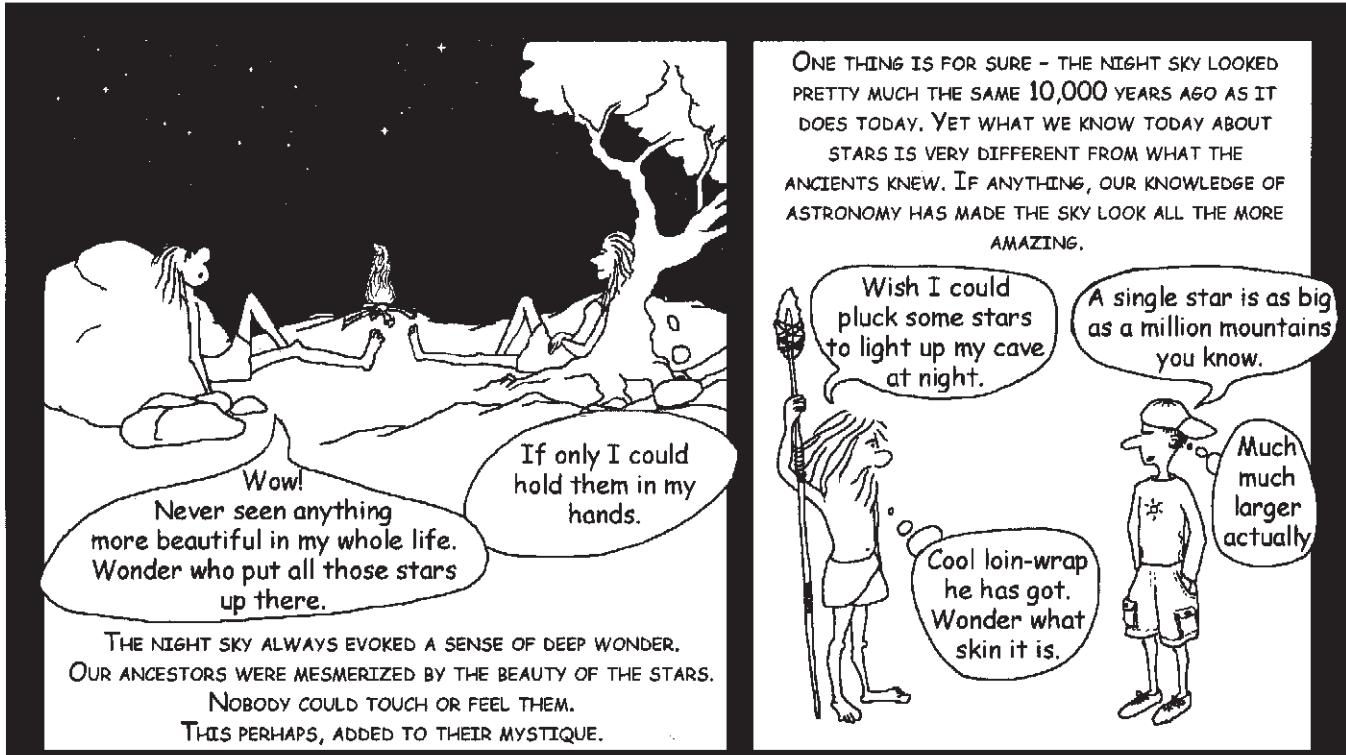
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STORY
OF
ASTRONOMY

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A Journey from Antiquity into the Future



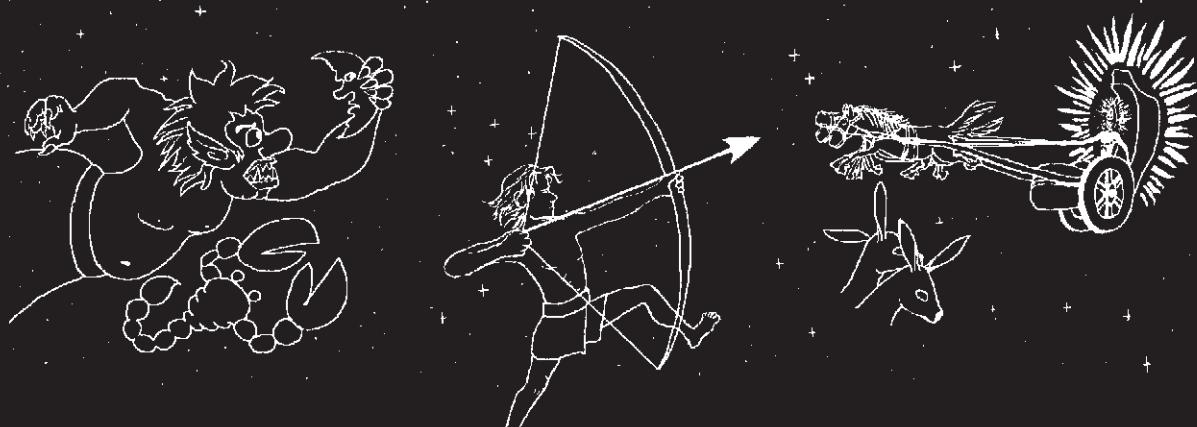
Drama in the Heavens



OUR ANCESTORS WERE MESMERIZED BY THE MAGNIFICENT NIGHT SKY. IT EVOKED A SENSE OF WONDER, AWE AND EVEN FEAR. THEY SAW THE STARS STREWN IN DIFFERENT PATTERNS. PEOPLE SAW OGRES, FISHES, ANIMALS AND LOVELY WOMEN IN THE STARS. THEY MADE BEAUTIFUL STORIES OUT OF THEM.

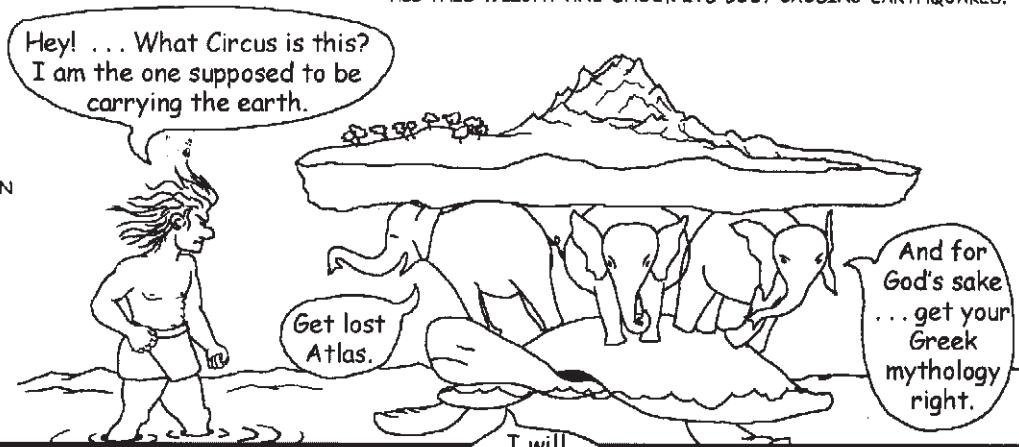
You can take the Neanderthal out of the Ice Age but you can't take the Ice Age out of the Neanderthal.

THE SUN, THE MOON AND THE STARS PLAYED AN IMPORTANT ROLE IN THE MYTHOLOGY AND THE FOLKLORE OF EVERY CULTURE.



THE INDIANS BELIEVED THAT OUR EARTH - A LARGE FLAT MASS, WAS SUPPORTED BY A PACK OF ELEPHANTS. THE ELEPHANTS IN TURN, STOOD ON THE BACK OF A GIANT TURTLE SWIMMING IN THE OCEAN. SOMETIMES THE TURTLE GOT TIRED CARRYING ALL THIS WEIGHT AND SHOOK ITS BODY CAUSING EARTHQUAKES.

THE GREEKS MADE THEIR OWN STORIES. TITANS WERE POWERFUL GODS IN GREEK MYTHOLOGY. ATLAS - THE TITAN WARRIOR WAS RESPONSIBLE FOR SUPPORTING THE SKY AND PREVENTING IT FROM FALLING ON EARTH.



SUCH STORIES WERE MORE THAN JUST A PRODUCT OF A FERTILE IMAGINATION. THEY WERE EARLY ATTEMPTS TO EXPLAIN THE UNIVERSE.

THEY FORMED THE EARLIEST COSMOLOGIES, OR THEORIES OF THE UNIVERSE.

It's Dark - Time to Make a Move

IN THE ABSENCE OF CALENDARS AND CLOCKS THE SKY ALSO SERVED AS A USEFUL REFERENCE FOR TIME AND DIRECTION.

IT HELPED NOMADS AND NAVIGATORS REACH THEIR DESTINATION.

Aren't we supposed to follow the pole star Ishmael?

It is mid day for God's sake. Till night fall we will have to go where the camels take us.

I think they are totally clueless.

How about taking them for a ride?

SAILORS ON THE HIGH SEAS FOUND THE SKY VERY USEFUL TOO. IN THE MIDST OF THE VAST OCEAN THE STARS HELPED THEM FIND THEIR BEARINGS.

DEVELOPMENT IN ASTRONOMY LED TO ADVANCES IN THE SCIENCE OF NAVIGATION. SAILORS COULD OBSERVE STARS MORE ACCURATELY AND CROSS THE OCEANS.

Damn these #@%& clouds.

Can't see a single star.

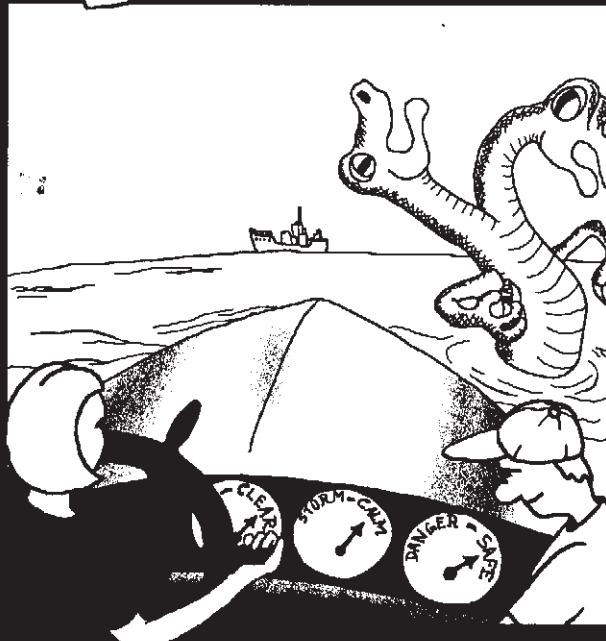
Splendid! Simply splendid!
Just when we were entering the Bermuda Triangle.

NAVIGATING BY STARS IS STILL PRACTICED.

HOWEVER, MODERN SHIPS AND BOATS USE NAVIGATION TECHNOLOGY COMPRISING OF SATELLITES, RADIO WAVES AND ELECTRONIC GADGETS TO STEER THEM THROUGH THE HIGH SEAS.

Jack ...
I think we are in big trouble

Just relax Jill.
For once, trust the gadgets.



That ain't no Star. It Moves!

THE SUN, THE MOON AND THE STARS ALL MOVED ACROSS THE SKY. THAT MUCH WAS COMMON KNOWLEDGE. BUT THERE WERE KEEN OBSERVERS WHO SAW PATTERNS.

The stars never stop moving, yet the patterns made by them are fixed.

Hmm... interesting. But that one up North doesn't move at all.

AND THEY SOUGHT OUT EXPLANATIONS.

The stars seem stuck to the inside of the sky, which keeps turning like a huge top.

That makes sense. And the 'North Star' happens to be situated exactly on the axis of this rotation.

THIS WAS THE BEGINNING OF ASTRONOMY AS A SCIENCE.

THE 'NORTH STAR' OR THE 'POLE STAR' - BECAUSE IT STOOD STILL AT ONE PLACE, ENJOYED A SPECIAL STATUS IN ANCIENT ASTRONOMY.

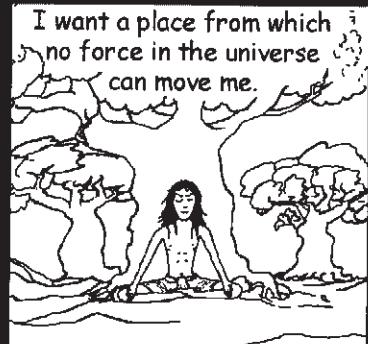
ALL THE OTHER STARS - THE ENTIRE CELESTIAL DOME, ROTATED AROUND THE 'POLE STAR'. THUS 'POLARIS' BECAME THE ANCHOR POINT FOR STUDYING THE NIGHT SKY.

IN INDIA, THE NORTH STAR IS CALLED DHRUVA AFTER THE MYTHOLOGICAL PRINCE WHO TRANSFORMED INTO THE STAR.

ONE DAY, FIVE YEAR OLD PRINCE DHRUVA WAS SITTING ON HIS FATHER'S LAP. DHRUVA'S STEPMOTHER, THE BEAUTIFUL BUT WICKED QUEEN, COULDN'T STAND THIS SIGHT. SHE PUSHED DHRUVA OFF HIS FATHER'S LAP TO MAKE PLACE FOR HER OWN SON.

Get lost, you brat! You are not the only prince around here.

DEEPLY HURT, DHRUVA LEFT HOME IN SEARCH OF A PLACE FROM WHERE HE COULDN'T BE DISLODGED. AFTER A LONG PENANCE, HE WAS TRANSFORMED INTO A STATIONARY STAR - FIXED AT ONE POINT IN SPACE.



DID ALL STARS MOVE IN A PATTERN?
Hey! You told me ALL stars stick to their pattern. But one yonder there wanders.

WELL . . . NOT ALL.
May be it just looks like a star but is really something else?

INDEED, A FEW BRIGHT STARS STRAYED FROM THE PATTERN. THE GREEKS CALLED THEM PLANETS WHICH MEANT WANDERERS. THESE WANDERING STARS KEPT DRIFTING ACROSS THE FIXED STELLAR PATTERN.

EVEN THE SUN AND THE MOON WERE NOT FIXED TO THE PATTERN OF STARS. THEY WANDERED TOO.

The Sun and the Moon are also planets. They wander too.

Even the Sun? How can you possibly tell?

THERE WERE FIVE STAR-LIKE PLANETS. THEY WERE NAMED AFTER GREEK GODS.

MERCURY

VENUS

MARS

JUPITER

SATURN

HEY, WHAT ABOUT US?



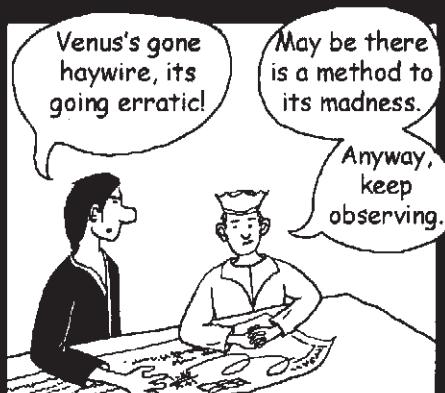
IF YOU ADDED TO THEM THE SUN AND THE MOON THEN THE NUMBER OF PLANETS INCREASED TO SEVEN.

Keeping Track of Time

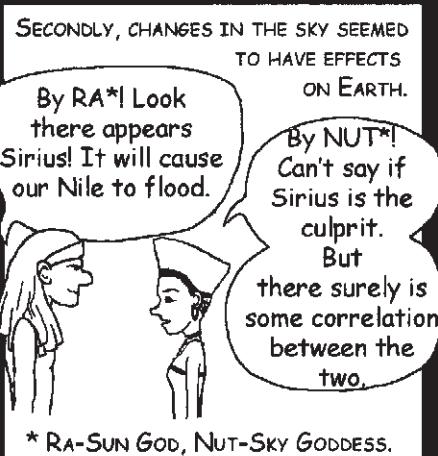
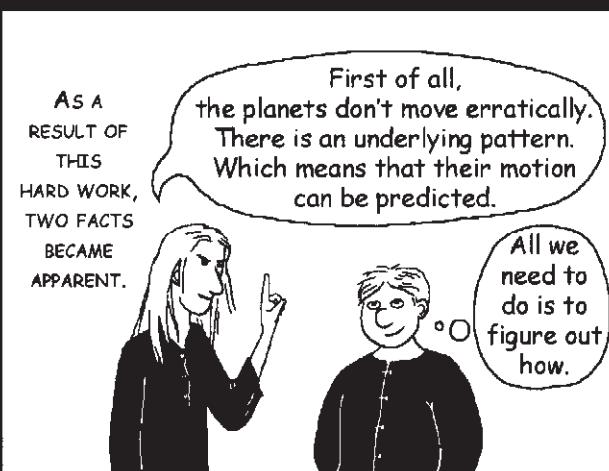
STAR PATTERNS MOVED PRETTY FAST. THEIR MOTION WAS NOTICEABLE WITHIN A FEW MINUTES. ON THE OTHER HAND THE RELATIVE MOTION OF PLANETS ON THE STELLAR TAPESTRY WAS MUCH SLOWER.



IT TOOK SEVERAL DAYS, OFTEN SEVERAL MONTHS OF CAREFUL OBSERVATION TO NOTICE THE MOVEMENT OF THE PLANETS. TO STUDY THEIR MOTION WAS LONG AND TEDIOUS.

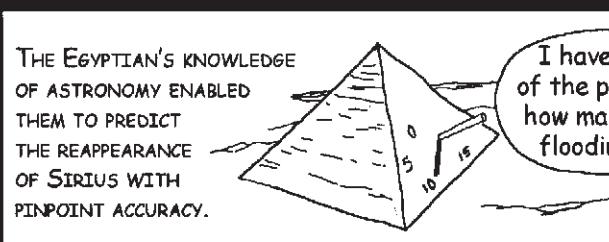


IT TOOK CENTURIES OF COLLECTIVE EFFORT BEFORE SOME PATTERNS STARTED EMERGING OUT OF PILES OF OBSERVED DATA.



IN EGYPT, LIFE WAS GOVERNED BY THE ANNUAL FLOODING OF NILE.

WHEN THEY SAW SIRIUS RISING JUST BEFORE THE SUN THEY KNEW IT WOULD SOON BE TIME FOR THE FLOODING - INUNDATION OF THE NILE.



I have perfected it. The shadow of the pole on that pyramid tells us how many days are left for the flooding of Nile.

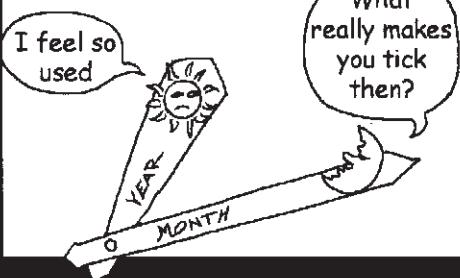
That is neat. Really neat. So let's see...
... Oh my God! It will be flooding in 10 days.

FOR SYSTEMATIC PREDICTION OF NATURAL PHENOMENA, A GOOD SYSTEM FOR TRACKING TIME WAS NEEDED. THIS GAVE BIRTH TO THE CALENDAR. THE CIRCLING OF THE SUN ACROSS THE STELLAR PATTERN MARKED ONE YEAR. ONE COMPLETE PHASE CYCLE OF THE MOON MARKED A MONTH.

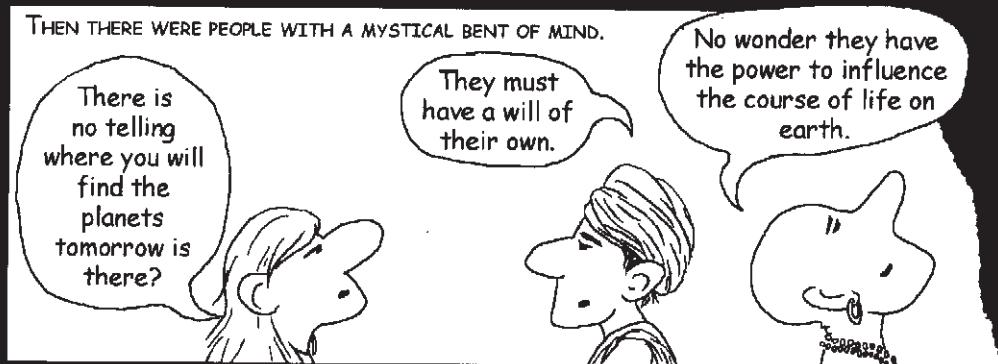
BOTH FARMING AS WELL AS ADMINISTRATION OF THE STATE COULD NOW BE PLANNED AND EXECUTED, LIKE CLOCK WORK.



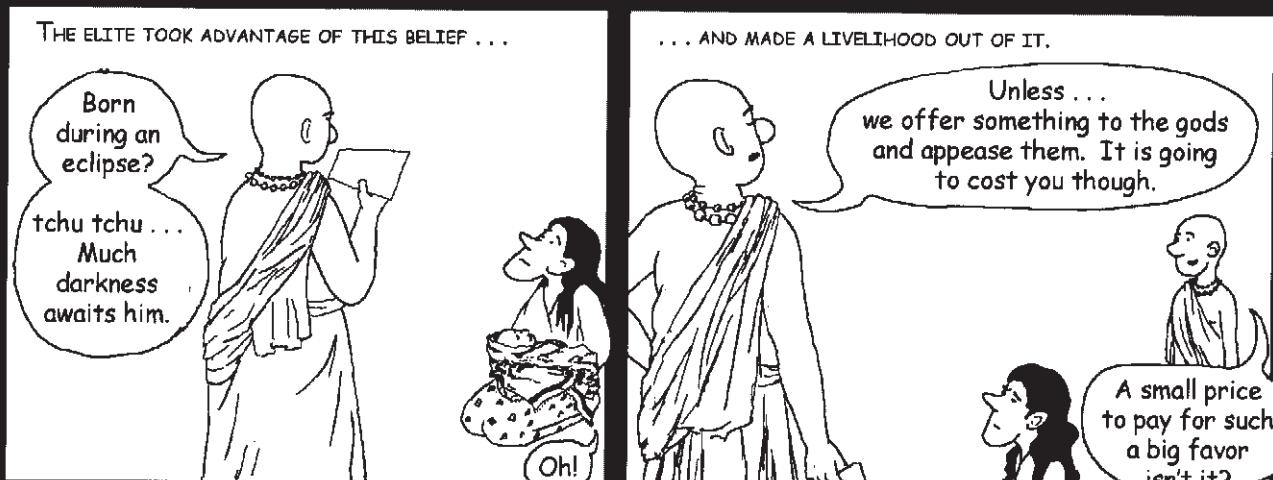
THE SUN, THE MOON AND THE STARS BECAME TIME KEEPERS. THEIR DAILY ROTATION AROUND THE EARTH TOLD THE TIME OF THE DAY WHILE THEIR WANDERING WITHIN THE STELLAR PATTERN INDICATED THE TIME OF THE YEAR.



Astrology



Thus ASTROLOGY WAS BORN. PEOPLE CAME TO BELIEVE THE PLANETS AFFECTED THEIR LIVES.



INDEED THERE WAS SOME EVIDENCE SUGGESTING THE INFLUENCE OF HEAVENLY BODIES ON EARTHLY PHENOMENA.



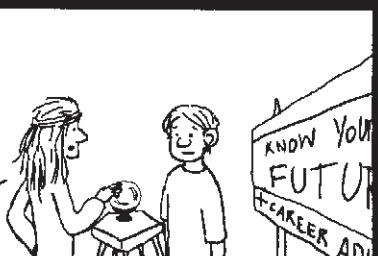
BUT ASTROLOGERS BLEW THIS OUT OF PROPORTION.



ASTROLOGY THRIVES EVEN TODAY, ESPECIALLY IN UNDERDEVELOPED COUNTRIES.

IN INDIA, THERE ARE MANY MORE ASTROLOGERS THAN ASTRONOMERS. SOME UNIVERSITIES EVEN OFFER DEGREE COURSES IN ASTROLOGY.

Astronomy did you say?
Not much future in the field.
Why don't you apply for an Astrology course instead?



Aristotle

ON THE OTHER HAND, THERE WERE THOSE WHO LOOKED AT THE SKY WITH A SCIENTIFIC INTEREST.

Why do stars form patterns? And why do planets wander?

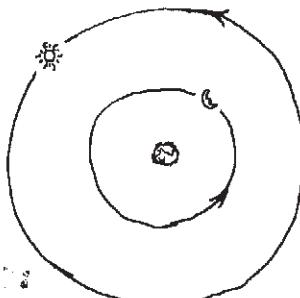
You mean there could be a reason behind why things are the way they are?

FOR ARISTOTLE, ASTRONOMY WAS A BRANCH OF PHILOSOPHY.

I believe the universe is spherical because the sphere is the most perfect shape.

HE HAD HIS OWN WAY WITH LOGIC.

The heavenly bodies move in circles, for a circle is the most perfect path possible.

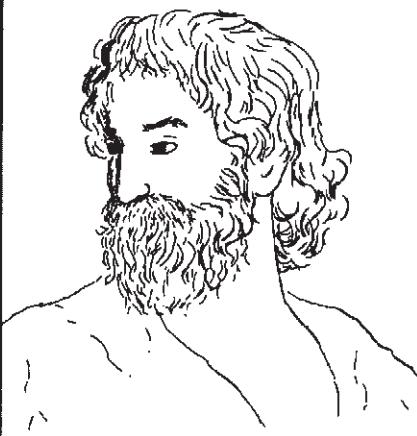


IT HAS BEEN SAID THAT ARISTOTLE'S IDEAS REMAIN THE MOST INFLUENTIAL THOUGHT SYSTEM EVER PUT TOGETHER BY A SINGLE MIND. HIS PHILOSOPHY SHAPED THE INTELLECTUAL DEVELOPMENT OF MANY CULTURES.

LIKE WITH MANY FIELDS, HIS IDEAS HAD A STRONG INFLUENCE ON ASTRONOMY. THE ROLE OF SPHERES AND CIRCLES WENT UNQUESTIONED FOR A GOOD TWO THOUSAND YEARS.

THE EVOLUTION OF MODERN ASTRONOMY CAN BE TRACED BACK TO THE WRITINGS OF ARISTOTLE, THE FAMOUS GREEK PHILOSOPHER.

ARISTOTLE 384 - 322 BC



THIS GREEK PHILOSOPHER WAS THE FIRST ONE TO FORMULATE A COMPREHENSIVE SYSTEM OF PHILOSOPHY. HIS WRITINGS COVERED A VARIETY OF TOPICS - POLITICS, MORALITY, AESTHETICS, METAPHYSICS, LOGIC AND SCIENCE. HE WAS THE FIRST ONE TO UNDERTAKE A FORMAL STUDY OF LOGIC.

HIS THOUGHTS HAD A STRONG INFLUENCE ON MANY PHILOSOPHICAL AND THEOLOGICAL TRADITIONS. ARISTOTELIAN PHILOSOPHY IS STILL AN ACTIVE FIELD OF STUDY.

HE INFLUENCED MANY PEOPLE IN HISTORY, THE MOST WELL KNOWN BEING HIS STUDENT ALEXANDER THE GREAT.

IT IS NOT CLEAR WHETHER ARISTOTLE'S INFLUENCE ON ASTRONOMY WAS A BOON OR A HURDLE. BUT HIS REAL CONTRIBUTION TO SCIENCE LIES IN THE TREND HE STARTED.

HE ASKED QUESTIONS ABOUT THE UNIVERSE. HE ATTEMPTED EXPLANATIONS FOR PHENOMENA THAT PEOPLE TOOK FOR GRANTED.

Models of Motion

TO TRACK THE WANDERING PLANETS PRECISELY, THE STELLAR PATTERN WAS CAREFULLY MAPPED.

What?

After dividing their land these silly men are now dividing the sky?



EACH REGION OF THE NIGHT SKY WAS IDENTIFIED WITH THE LOCAL PATTERN OF BRIGHT STARS CALLED A CONSTELLATION.

MAPPING THE STELLAR PATTERN MADE IT POSSIBLE FOR THE MOTION OF PLANETS TO BE MEASURED WITH ACCURACY. THE NEXT STEP WAS TO UNDERSTAND THIS MOTION.

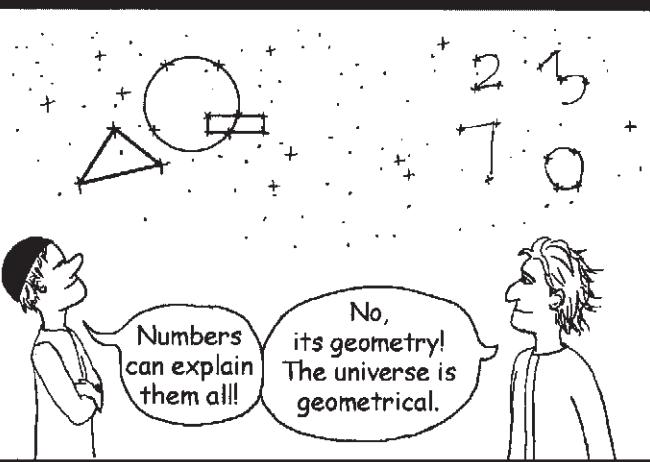
I can't make head or tail of this movement of planets. I think they are possessed.

ASTRONOMERS STROVE HARD TO IDENTIFY SIMPLE

PRINCIPLES THAT COULD EXPLAIN THE COMPLEX MOTION OF PLANETS.

I think they just look complex. May be there are simple principles underlying their motion. We must try to figure them out.

IN TRYING TO MAKE SENSE OF THE MOTION OF PLANETS ASTRONOMERS USED MATHEMATICS.



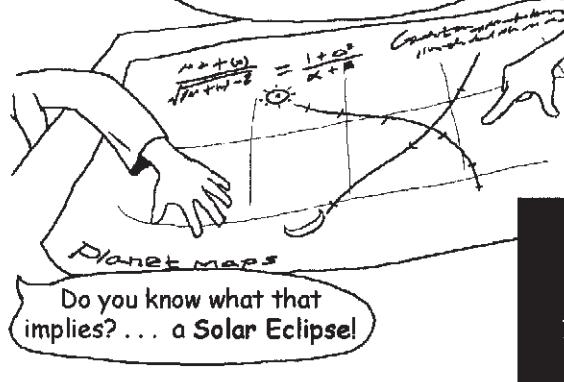
ASTRONOMERS TRIED TO EXPLAIN THE MOTION OF PLANETS USING SIMPLE MATHEMATICAL MODELS. IT MEANT USING A FORMULA TO TELL THE POSITION OF THE PLANET AT ANY GIVEN TIME.

IF SUCH A MODEL COULD ACCURATELY LOCATE THE POSITION OF A PLANET A FEW HUNDRED YEARS BACK IT SHOULD ALSO HELP IN PINPOINTING ITS POSITION IN THE DISTANT FUTURE TOO.

THE SUCCESS (OR ACCURACY) OF THESE MODELS DEPENDED ON THE SOPHISTICATION OF THE MATHEMATICS INVOLVED. THE EGYPTIAN MODELS WERE BASED ON A PRIMITIVE NUMBER SYSTEM. THEY WERE NOT VERY SUCCESSFUL.

THE BABYLONIANS DID BETTER BECAUSE OF THE WAY THEY REPRESENTED NUMBERS. THEIR SCHEME WAS QUITE SIMILAR TO THE MODERN DECIMAL SYSTEM. INSTEAD OF 10 THEY USED A BASE OF 60. THE LEGACY OF THE BABYLONIANS STILL Lingers ON. AN HOUR IS DIVIDED INTO SIXTY MINUTES AND EACH MINUTE INTO SIXTY SECONDS.

Look.
According to this model,
the Sun will cross the Moon's paths exactly at mid-day,
next month.



BEING ABLE TO PREDICT THE MOTION OF THE PLANETS WELL IN ADVANCE MEANT A LOT. SOLAR AND LUNAR ECLIPSSES, THOUGHT TO BE RANDOM PHENOMENA UNTIL THEN, BECAME PREDICTABLE. ECLIPSSES WERE IMPORTANT EVENTS IN RELIGION. NATURALLY, RELIGIOUS ACTIVITIES GOT MIXED WITH ASTRONOMY.

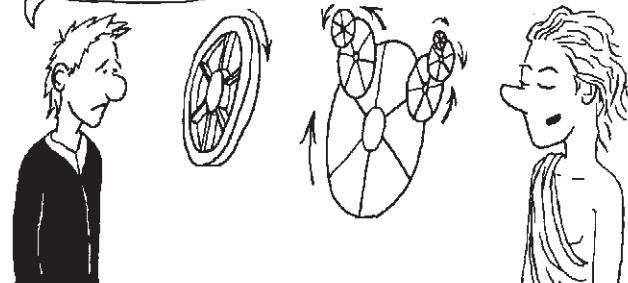
MATHEMATICS PLAYED AN IMPORTANT ROLE IN THE DEVELOPMENT OF ASTRONOMY. IN TURN, ASTRONOMY WAS THE DRIVING FORCE THAT LED TO MAJOR ADVANCES IN MATHEMATICS.

Wheels of Motion

THE INITIAL MODELS OF PLANETARY MOTION WERE CIRCULAR.

How can simple circles explain the complex motion of a planet?

Isn't it fascinating? A combination of simple motions can be very complex.



THE FIRST MODELS WERE BASED ON CONCENTRIC SPHERES. THESE SPHERES TURNED UNIFORMLY ON THEIR AXES LIKE TOPS. THE AXIS OF ONE SPHERE WAS FIXED IN ANOTHER.

24 hours

3200 years

28 days

15 years

100 years

1000 years

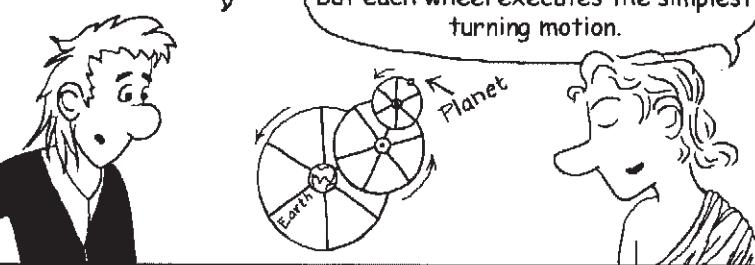
10000 years

EACH PLANET REQUIRED SEVERAL CONCENTRIC SPHERES TO MODEL ITS MOTION.

THEN THERE WERE EPICYCLES. IN THIS MODEL, EACH PLANET WAS FIXED ON A TURNING WHEEL, WHOSE CENTER WAS FIXED ON ANOTHER TURNING WHEEL (WHICH IN TURN MIGHT HAVE BEEN ATTACHED ONTO ANOTHER TURNING WHEEL).

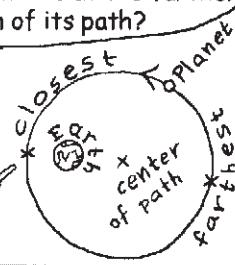
Now that surely can give rise to complex motion.

Epicycles are beautiful. The whole machine may look complex, but each wheel executes the simplest turning motion.



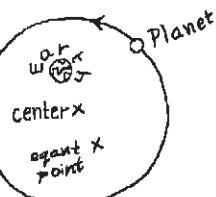
YET ANOTHER CONCEPT WAS THE ECCENTRIC CIRCLE. IT HELPED TO EXPLAIN THE SPEED VARIATIONS OF PLANETS.

See how a uniformly moving planet appears faster when it is close to us and slower when it is at the farther portion of its path?



AMONGST THE CIRCLE BASED MODELS THE EQUANT POINT WAS THE MOST COMPLEX CONSTRUCT. IT ALSO TURNED OUT TO BE THE MOST POWERFUL TOOL IN MODELING PLANETARY MOTION. IT WAS USED FOR OVER A MILLENNIUM AND A HALF.

The planet orbits along an eccentric circle but not uniformly. However, its motion appears uniform if viewed from a particular point in space. I call this point the Equant Point.



That's awfully complicated. But ... what ever works ...

COLLECTIVELY, THESE MODELS QUITE SUCCESSFULLY CAPTURED THE MOTION OF THE PLANETS. THE SPHERES AND THE CIRCLES WERE STILL ONLY MENTAL CONSTRUCTS AND NOT PHYSICAL ENTITIES. BUT THEY HELPED IN BUILDING SIMPLE YET PRECISE MODELS.

THE PREDICTIVE ABILITIES OF MODELS DECIDED THEIR SUCCESS OR FAILURE.

THE GREEK ASTRONOMER, PTOLEMY, WAS THE FIRST TO COMBINE ALL THESE MODELING TECHNIQUES. HE WORKED OUT THE FIRST ACCURATE MODEL TO EXPLAIN THE MOTION OF PLANETS.

Ptolemy - the Greek Astronomer from Egypt

PTOLEMY WAS A GREEK ASTRONOMER. HIS ACTUAL NAME WAS CLAUDIUS PTOLEMAEUS. NOT MUCH IS KNOWN ABOUT HIS PERSONAL LIFE.

Well... I am Greek but lived in Egypt. And I authored the Almagest.

What more do you wish to know?



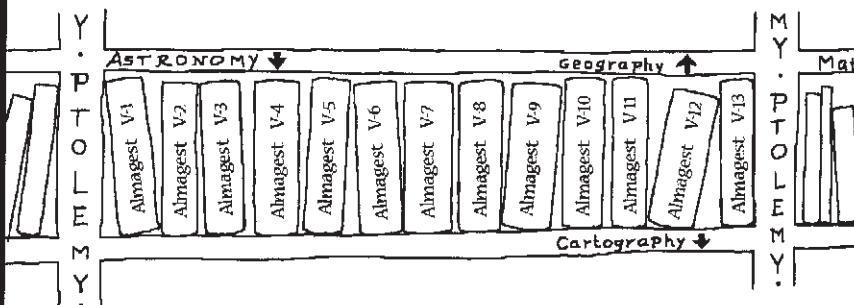
ALMAGEST IS THE POPULAR NAME OF THE BOOK PTOLEMY WROTE. THE ORIGINAL TITLE IN GREEK, MEGALE SYNTAXIS MEANT MATHEMATICAL COMPILATION. IT WAS LATER TRANSLATED INTO ARABIC WITH THE NAME AL MAJISTI (OR THE GREATEST) AND THEN LATER INTO LATIN WITH THE NAME ALMAGESTUM.

IT WAS INDEED A MAGNIFICENT TREATISE ON ASTRONOMY.

CLAUDIUS PTOLEMAEUS 85-165 AD



THE ALMAGEST WAS AN EXTENSIVE WORK FILLING 13 VOLUMES. IT CATALOGUED 1000 STARS AND VARIOUS PHENOMENA OBSERVED IN THE SKY.



MOST IMPORTANTLY, IT WAS A COMPILATION OF TECHNIQUES BY PAST ASTRONOMERS AS WELL AS PTOLEMY'S OWN INVENTIONS IN MODELING PLANETARY MOTION.

PTOLEMY LIVED IN ALEXANDRIA (EGYPT). HE WAS AN ASTRONOMER, MATHEMATICIAN, GEOGRAPHER AND CARTOGRAPHER. HE WAS THE AUTHOR OF THE FIRST TREATISE ON ASTRONOMY POPULARLY KNOWN AS ALMAGEST.

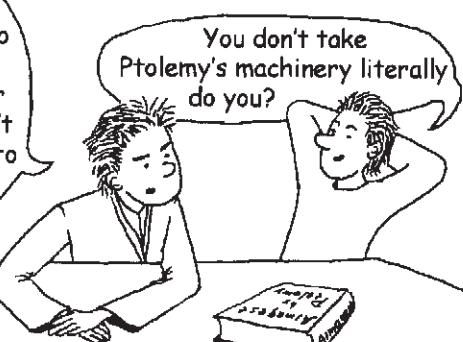
HIS WORK IN ASTRONOMY REIGNED SUPREME FOR 1400 YEARS.

THE SUCCESS OF PTOLEMY'S WORK LAY IN THE PREDICTIVE POWER OF HIS MODELS.

BUT THERE WERE PROBLEMS.



If the epicycles bring the planets so close to Earth and then take them far away, then why don't the planets appear to grow big and then shrink?



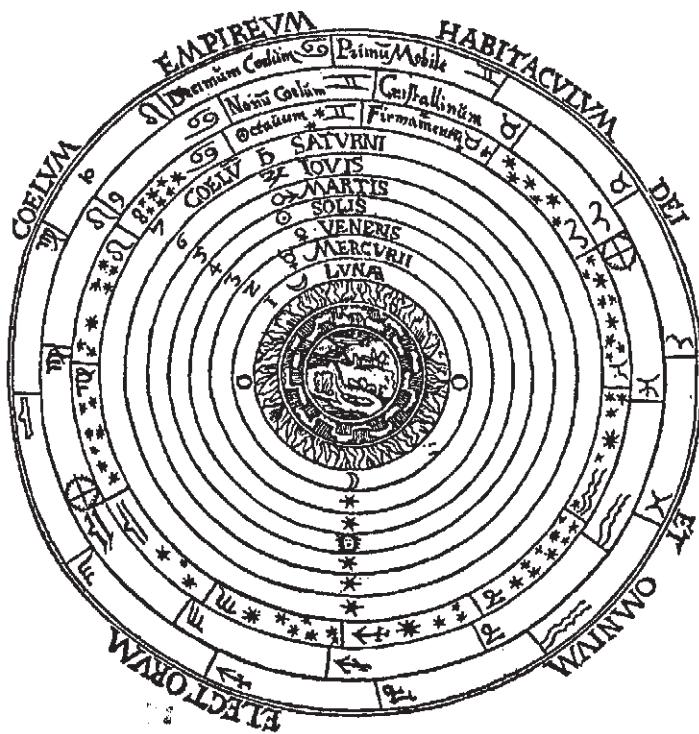
IT WAS ACCEPTED THAT THE EPICYCLES, THE EQUANT POINTS AND ALL THE MACHINERY OF PTOLEMY'S MODELS WERE ONLY MENTAL CONSTRUCTS. THEY ONLY MODELED THE OBSERVED MOVEMENT OF PLANETS AND NOT THE PHYSICAL REALITY.

Ptolemy's Universe

THE UNIVERSE DESCRIBED BY PTOLEMY WAS EARTH CENTRIC. THE SUN, THE MOON AND THE STAR LIKE PLANETS REVOLVED AROUND EARTH ACCORDING TO A CONCEPTUAL MACHINERY MADE UP OF EPICYCLES AND EQUANT POINTS. EACH PLANET OCCUPIED A DISTINCT SPHERICAL SHELL. ALL THE STARS WERE FIXED TO A ROTATING SPHERE JUST BEYOND THE FARTHEST PLANET.

APART FROM MINOR MODIFICATIONS, THE PTOLEMIC MODEL OF THE COSMOS SURVIVED PRACTICALLY UNALTERED FOR OVER 1400 YEARS. DURING THESE CENTURIES, ALMAGEST WAS TRANSLATED AND READ LIKE A BIBLE ACROSS THE WORLD. IT WAS TREATED AS THE ULTIMATE WORK ON ASTRONOMY.

Schema huius præmissæ diuisionis Sphærarum.

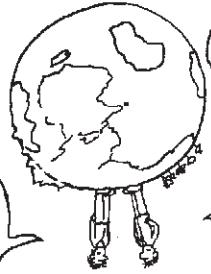


IN LIGHT OF
OUR CURRENT KNOWLEDGE,
PTOLEMY'S UNDERSTANDING OF THE UNIVERSE WAS
GROSSLY ERRONEOUS. BUT DURING HIS TIME (AND
FOR CENTURIES TO COME) THIS VIEW OF THE COSMOS
WAS TREATED AS THE GOSPEL.

IT TOOK THE
COMBINED EFFORTS OF
SEVERAL BRILLIANT PEOPLE TO CHALLENGE
PTOLEMY'S MODEL. THE BRAVE VIEWS OF COPERNICUS, THE
ELLIPTICAL ORBITS OF KEPLER AND THE TELESCOPE INVENTED BY
GALILEO FINALLY TRASHED PTOLEMY'S WORLD-VIEW AND PUT
AN END TO THE DARK AGES OF ASTRONOMY.

Flat Earth - Round Earth

By 1000 BC, ASTRONOMERS HAD FIGURED THAT THE EARTH WAS NOT A FLAT DISK BUT A ROUND BALL.

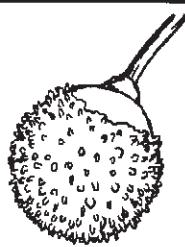


If Earth is round like a ball, then how come it looks so flat?

I say, I tell you... These astronomers fall off? If you went under this would happen to earth's surface? And what would happen if you went down?

ARYABHATA,
THE FAMOUS
INDIAN
ASTRONOMER
(500 AD)
GAVE A
BEAUTIFUL
ANALOGY
TO VISUALIZE
HOW THE EARTH
WOULD LOOK FROM
FAR AWAY.

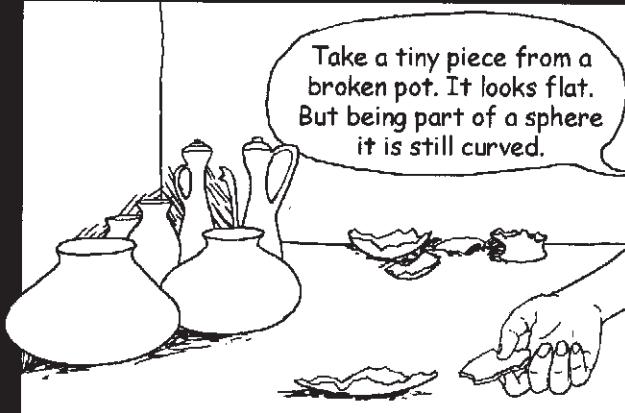
Like tiny flowers popping out of the ball-like fruit of the Kadamba tree....



we stand on the surface of a spherical earth - down being towards; and up meaning away from its center.

BUT IF THE EARTH IS LIKE A BALL, THEN WHY DOES IT APPEAR FLAT?

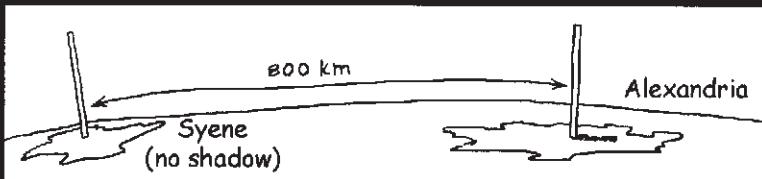
THERE ARE GOOD REASONS FOR THAT.



THEN WHAT MADE SOME PEOPLE INSIST THAT EARTH WAS A GIANT BALL? THERE WAS EVIDENCE . . . SOLID EVIDENCE.



BUT HOW BIG WAS THE EARTH? THE GREEK SCHOLAR ERATOSTHENES FIGURED IT OUT AROUND 240 BC. IF THE EARTH WAS A SPHERE THEN THE SUN'S LIGHT SHOULD STRIKE DIFFERENT PLACES AT DIFFERENT ANGLES. IT WAS KNOWN THAT A VERTICAL POLE IN SYENE (NEAR EGYPT) CAST NO SHADOW ON JUNE 21 AT NOON. ERATOSTHENES MEASURED THE SHADOW CAST BY ANOTHER POLE ON THE SAME DAY AT NOON IN ALEXANDRIA - A PLACE 800 KM FROM SYENE,



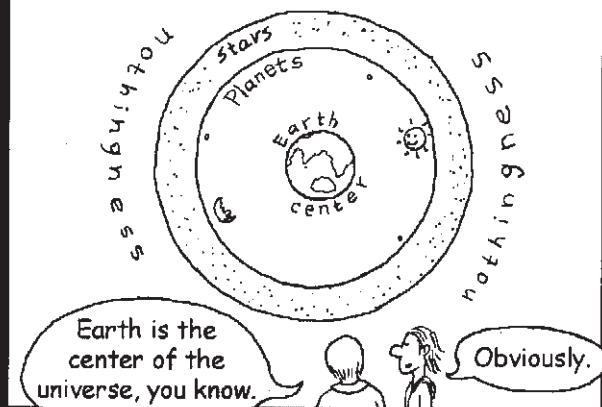
WITH THIS INFORMATION ERATOSTHENES EASILY CALCULATED THE CIRCUMFERENCE OF EARTH AS 40,000 KM.

Who could have imagined? The earth we live on . . . a giant ball . . . its circumference a staggering 40,000km . . . and which is open to the sky on all sides.

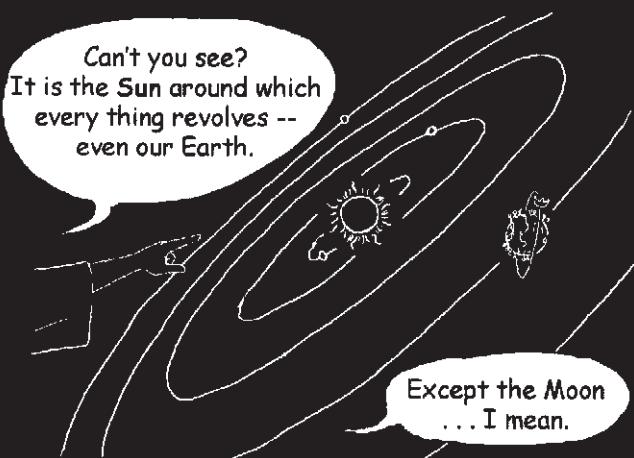


The Geocentric Theory

THE SUN, THE MOON, THE PLANETS AND EVEN THE STARS ALL SEEM TO REVOLVE AROUND US. NATURALLY, THE EARLY ASTRONOMERS THOUGHT THE EARTH WAS THE CENTER OF ALL THIS MOTION.



QUITE EARLY IN HISTORY, MANY THINKERS THOUGHT THAT IT WAS THE SUN (AND NOT THE EARTH) AROUND WHICH THE EARTH AND OTHER PLANETS REVOLVED. AROUND 250 BC, ARISTARCHUS OF SAMOS (IN GREECE) SAID . . .



UNFORTUNATELY, SUCH THEORIES FELL ON DEAF EARS. THE WORLD, IT SEEMS WAS STILL NOT READY FOR SUCH RADICAL IDEAS.

That's junk... Everybody knows that it is the Sun that revolves around the Earth and not the other way.

Yeah. I mean . . . why don't they work on something useful instead of messing with obvious truths?

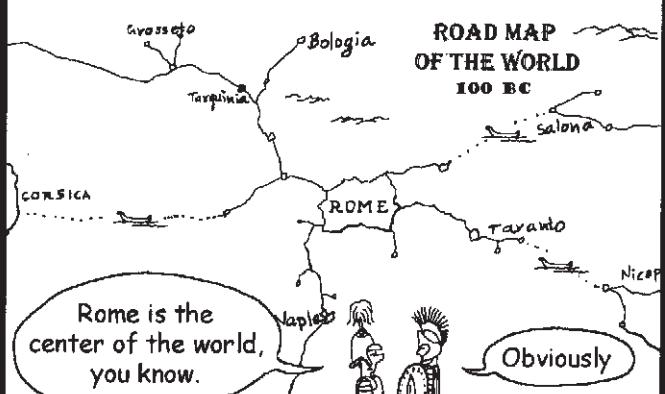
SO, FOR SEVERAL THOUSANDS OF YEARS THE EARTH WAS TO REMAIN THE CENTER OF THE UNIVERSE

AND THE SUN WAS MADE TO REVOLVE AROUND IT.

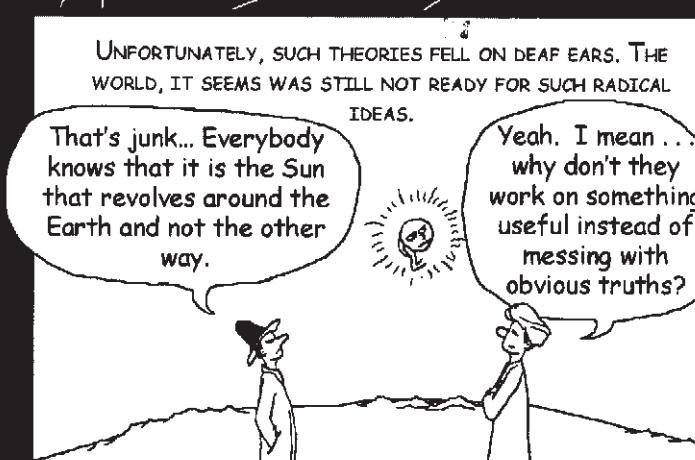
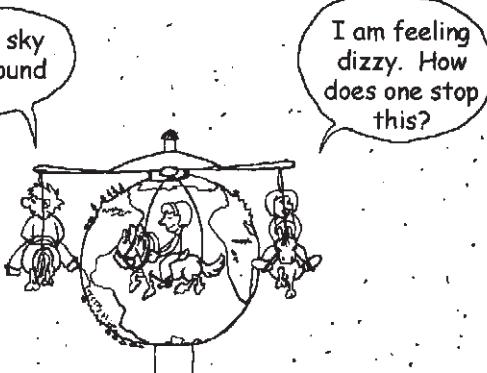
When will they get the picture right?

Don't waste your energy. It is going to be a long while before that will happen. Keep circling me for now.

TODAY WE KNOW THAT THE EARTH IS NOT THE CENTER OF THE UNIVERSE. IN FACT THERE IS NO SUCH THING AS THE CENTER OF THE UNIVERSE. THE IDEA IS AS SILLY AS THE ROMANS BELIEVING THAT ROME WAS THE CENTER OF THE WORLD.



AROUND 500 AD, ARYABHATA ARGUED THAT THE EARTH SPUN ON ITS OWN AXIS, LIKE A TOP, COMPLETING ONE ROTATION EVERY DAY. HE SAID IT WAS THIS ROTATION WHICH MADE THE STARS AND PLANETS APPEAR TO BE REVOLVING AROUND US. (IT IS LIKE HOW A MERRY-GO-ROUND MAKES THE WORLD SPIN.)



Copernicus

THE CREDIT GOES TO NICHOLAS COPERNICUS, FOR FINALLY STOPPING THE SUN AND SETTING THE EARTH INTO MOTION.

Pwho... at last!
Thanks Nicholas.
I couldn't have taken it
much longer.

Hey, don't push me.
I need some warming
up you know.

It had to happen some
day. Don't worry, I will
always be there with you.

ASTRONOMERS WERE
DISSATISFIED WITH
EXISTING MODELS.

PTOLEMY'S MODELS (CENTURIES OLD) NEEDED REFINEMENT,
OR REPLACEMENT.

Why
can't I
ever get
things
right?

I feel we are
barking up the
wrong tree.

Yeah. And what about the
size of the Moon? Why
doesn't it appear huge when it
comes close to us as the
model says?

I am really
tired of this
retrograde
motion you
know.

Somebody
help us
... please.

This kind
of error is not
acceptable.

Epicycles are mere
models. What do the
planet paths
really look like?

May be our
mathematics
is poor.

COPERNICUS WAS COURAGEOUS ENOUGH TO
CHALLENGE THE DOMINANT, UNQUESTIONED THEORY
OF HIS TIME. HE SAID:

Ptolemy's models can not be
improved any further. The basic premise of
his theory is faulty.

If the Sun is
placed at the
center of all
motion, then
everything will
become simple.
Follow evidence
and challenge
age-old
established
truths.

HE SPENT 30 YEARS WORKING OUT THE MATHEMATICAL DETAILS
OF HIS NEW SCHEMA.

The retrograde motion of
planets is an illusion caused
by the motion of our own
Earth around the Sun.

See, it is so
simple yet so
accurate.

Venus and Mercury
orbit the Sun too, just like
our Earth. They stick close to
the Sun because their orbits
are smaller.

HIS THEORY
DEMYSTIFIED SEVERAL COMPLICATED ASPECTS OF PLANETARY MOTION.
HIS CONTEMPORARIES HOWEVER FAILED TO APPRECIATE HIS WORK.

It took more than a century for Copernicus's ideas to be accepted. The Sun Centric (Heliocentric) model was a radical departure from the Earth Centric model. Astronomy finally emerged out of its dark ages. Copernicus is now universally recognized as the father of modern astronomy.

NICOLAUS COPERNICUS 1473-1543

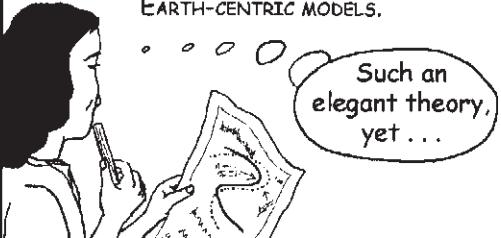


BORN IN POLAND HE WAS A
MATHEMATICIAN, ASTRONOMER,
PHYSICIAN, TRANSLATOR, ECONOMIST,
MILITARY LEADER AND MUCH MORE. HE
WAS THE FIRST TO PROPOSE A
SCIENTIFICALLY BASED HELIOCENTRIC
COSMOLOGY. HIS TREATISE TITLED DE
REVOLUTIONIBUS ORBium
COELESTIUM (ON THE REVOLUTION OF
THE CELESTIAL SPHERES) WAS THE
HARBINGER OF MODERN ASTRONOMY.

ANCIENT PHILOSOPHERS HAD
CONJURED ONLY A FUZZY
PICTURE OF THE HELIOCENTRIC
UNIVERSE. COPERNICUS'S THEORY,
ON THE OTHER HAND WAS NOT
JUST AN IDEA BUT A COMPLETE
SET OF SOLUTIONS.

The Heliocentric Theory

UNFORTUNATELY, THE COPERNICAN MODELS (BASED ON HIS SUN-CENTERED THEORY) DID NOT PROVE TO BE AN IMPROVEMENT OVER PTOLEMY'S EARTH-CENTRIC MODELS.



THE REASONS WERE TWOFOLD.

FIRSTLY, COPERNICUS DID NOT RECOGNIZE THE ELONGATED NATURE OF THE ORBITS. INSTEAD HE WORKED OUT A COMPLEX STRUCTURE OF EPICYCLES. SECONDLY, HE WORKED ON FAULTY OBSERVATIONS.

Who says this is simplification?

I don't get it.
Such radical ideas, yet such sloppy details.

THE PRACTICAL PROBLEMS RELATED TO PREDICTION WERE NOT THE ONLY ISSUES. THERE WERE CONCEPTUAL ONES TOO.

If we are all orbiting the Sun at such a tremendous speed, then how come I don't feel a thing?

Yeah. And who pushes such a huge ball of land around the Sun anyway?

Tell me... If the Earth is going from place to place, wouldn't we see some parallax* in the stellar pattern?

Parallax?
What is that?



*SEE PAGE 32 FOR A DISCUSSION ON PARALLAX.

ANSWERS TO SUCH FUNDAMENTAL QUESTIONS CAME MUCH LATER. THEY NOT ONLY ELIMINATED DOUBTS ABOUT THE HELIOCENTRIC THEORY BUT ALSO PROVIDED DEEPER INSIGHT INTO THE WORKING OF THE UNIVERSE.

BUT FOR NOW, THEY POSED A HURDLE TO THE COPERNICAN PICTURE.

NOT ALL PEOPLE DOUBTED COPERNICUS. IN FACT, HE HAD A HUGE FAN CLUB.

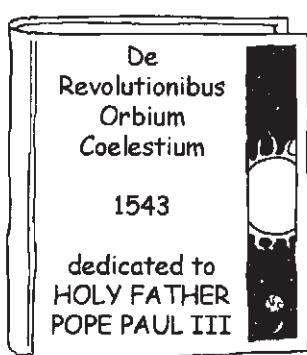
You should certainly publish your theory. The world deserves it.

I don't know. I still need to work out many details. Moreover...



COPERNICUS'S REAL FEAR WAS REJECTION BY THE CHURCH.

COPERNICUS KNEW IF THE CHURCH REJECTED HIS IDEAS THEN ONLY THE GOOD LORD COULD SAVE THEM. HE CERTAINLY DIDN'T WANT TO OFFEND THE CHURCH. HIS ASSISTANT - A REALLY SMART CHAP - PLAYED IT SAFE AND STILL BROUGHT OUT THE BOOK.



UNFORTUNATELY, THE BOOK FAILED TO GAIN THE POPULARITY IT DESERVED. COPERNICUS'S THEORY LANGLISHED FOR MORE THAN A CENTURY. BUT THE MERITS OF THE HELIOCENTRIC THEORY COULDN'T BE IGNORED COMPLETELY. NOT SURPRISINGLY, ASTRONOMERS FOUGHT HARD TO PROTECT THE GOOD OLD GEOCENTRIC PICTURE.

Copernicus has a point. We better do something about it.

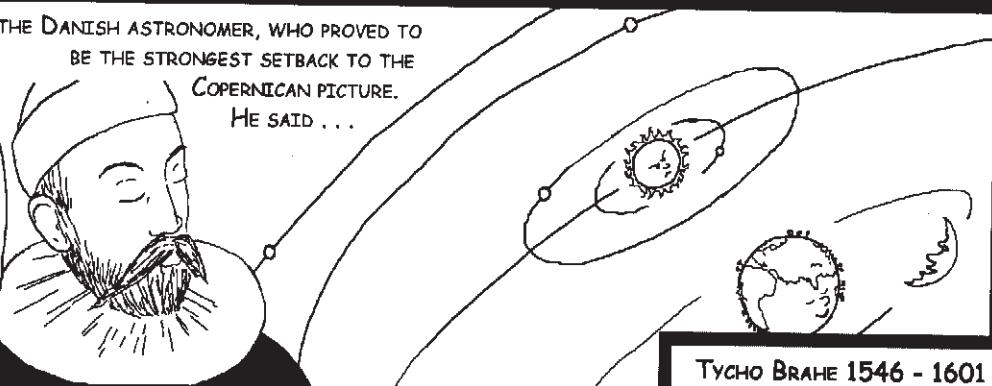
Yes. Otherwise we will lose terra firma* once and for all.

* FIRM GROUND

Tycho

IT WAS TYCHO BRAHE, THE DANISH ASTRONOMER, WHO PROVED TO BE THE STRONGEST SETBACK TO THE COPERNICAN PICTURE. HE SAID ...

True.
All planets orbit the Sun, except the Earth and the Moon. In fact the Sun, along with its pack of satellites revolves around a fixed Earth, (which of course is the true center of the universe).



TYCHO BRAHE 1546 - 1601



TYCHO'S ATTACK ON THE COPERNICAN PICTURE WAS, IN SOME SENSE, PERFECT. IT RETAINED EVERYTHING FROM THE COPERNICAN THEORY AND YET MANAGED TO PUT THE EARTH BACK INTO THE CENTER OF THE UNIVERSE. IN FACT, TYCHO'S PICTURE WAS IDENTICAL TO THAT OF COPERNICUS IN TERMS OF RELATIVE MOTION OF THE PLANETS, AND RELATIVE MOTION WAS ALL THAT COULD BE OBSERVED.

WHAT TYCHO REALLY DID, WAS TO SHIFT THE COORDINATE SYSTEM. HE TOOK THE COPERNICAN MOTION OF PLANETS BUT MADE EARTH THE CENTER FOR DESCRIBING THIS MOTION. A SHIFT IN THE COORDINATE SYSTEM DOES NOT AFFECT ANY RELATIVE MOTION.

THUS,

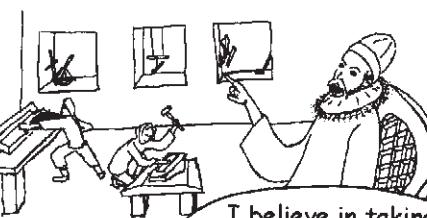
TYCHO BOTH SIDELINED THE COPERNICAN THEORY AND ALSO INCORPORATED IT COMPLETELY INTO HIS OWN.

HE FAILED TO SEE THE SUN AS THE CENTER. BUT HIS CONTRIBUTION TO ASTRONOMY WAS SIGNIFICANT IN ITS OWN RIGHT. HE WAS THE FIRST TO GIVE PRIME IMPORTANCE TO ACCURACY OF OBSERVATIONS.



If your observations are erroneous, your theory is bound to be faulty. Just look at Copernicus."

TYCHO DID NOT HAVE MUCH TRUST IN THE EXISTING DATA.



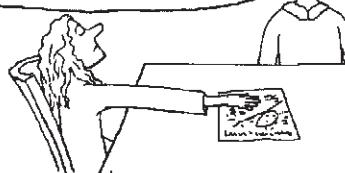
I believe in taking full responsibility for my theories you know.

BORN IN DENMARK. BUILT THE URANIBORG OBSERVATORY (HEAVENLY CASTLE) - THE FIRST MODERN RESEARCH INSTITUTE. HE WAS PASSIONATE ABOUT PRECISE OBSERVATIONS.

A MAJOR PART OF HIS LIFE WAS SPENT MAKING ACCURATE OBSERVATIONS AS WELL AS IN BUILDING PRECISION INSTRUMENTS.

TYCHO WORKED WITH A TEAM OF ASSISTANTS FOR OVER A DECADE. THE DATA HE COLLECTED SERVED AS A RELIABLE SOURCE OF INFORMATION FOR FUTURE ASTRONOMERS.

Let me make it clear to you... this data is from Tycho. If your model shows a deviation then blame your model not the data.

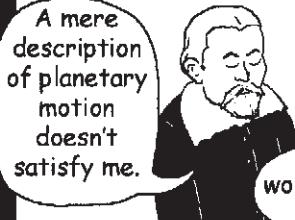


LATER
TYCHO INVITED YOUNG KEPLER TO ASSIST HIM IN HIS WORK. THIS ARRANGEMENT HAD A PROFOUND IMPACT ON THE FUTURE OF ASTRONOMY.

KEPLER FOUND TYCHO'S DATA EXTREMELY USEFUL TO SUPPORT HIS OWN LAWS OF PLANETARY MOTION. KEPLER'S WORK PLAYED A DECISIVE ROLE IN ESTABLISHING THE HELIOCENTRIC PICTURE ONCE AND FOR ALL.

Kepler 1571 - 1630

Tycho's successor, Johannes Kepler thought modeling motion was not enough.



What else would you like to do Johannes?

I want to know why the planets move the way they do. What force keeps them on their paths?

Don't they move according to God's will?

Does he mean planetary motion is a matter of Physics and not just Geometry?

UNFORTUNATELY, KEPLER'S IDEAS ON THE PHYSICAL BASIS OF PLANETARY MOTION REMAINED VAGUE. IN LIGHT OF OUR CURRENT UNDERSTANDING, THEY WERE SIMPLY FAULTY.

The Sun emits a magnetic force which circulates and keeps the planets in motion. In its absence the planets will come to an instant halt.

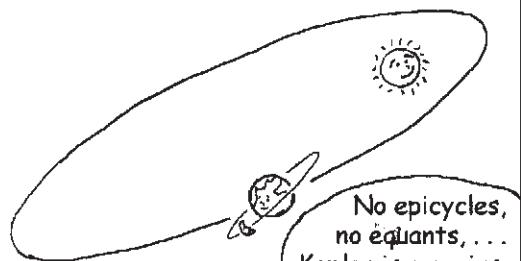
How interesting!

And how magical!

BUT HIS MODELING OF PLANETARY MOTION WAS SIMPLY PHENOMENAL. IN THE BEGINNING OF THE 17TH CENTURY, KEPLER PRESENTED THE WORLD WITH THREE NEW LAWS.

THEY ARE NOW POPULARLY KNOWN AS KEPLER'S LAWS. THEY PLAYED A FUNDAMENTAL ROLE IN THE FIRST SUCCESSFUL PHYSICAL THEORY OF THE UNIVERSE THAT EMERGED DURING THE FOLLOWING DECADES.

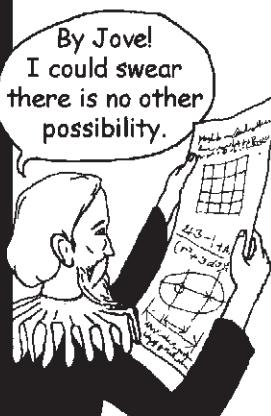
IT WAS THE MARK OF A GENIUS WHEN HE REPLACED THE COMPLICATED MACHINERY OF EPICYCLES WITH JUST ONE CURVE, THE ELLIPSE, TO DESCRIBE A PLANETARY ORBIT.



Yes, it's frightfully simple, yet deadly accurate.

KEPLER'S ORBITAL MODEL WAS STARKLY SIMPLE AND DEADLY ACCURATE. THE ELLIPTICAL ORBIT CAME TO BE KNOWN AS KEPLER'S FIRST LAW.

INTERESTINGLY ENOUGH, TYCHO'S DATA, WHICH KEPLER HAD DIRECT ACCESS TO, PLAYED A CRUCIAL ROLE IN HIS ACHIEVEMENTS. THE PRECISION OF THIS DATA CONVINCED KEPLER OF THE ERRONEOUS NATURE OF THE MODELS BASED ON EPICYCLES. SO HE SOUGHT NEW ALTERNATIVES (AND PICKED THE ELLIPSE).



TYCHO'S DATA WAS THE BEST ONE COULD HAVE OBTAINED USING THE NAKED EYE. BUT IT WAS NOTHING COMPARED TO THE PRECISION ACHIEVED DURING LATER DECADES THROUGH THE USE OF THE TELESCOPE.

IF KEPLER HAD ACCESS TO TELESCOPIC DATA, HE WOULD HAVE REALIZED THAT PLANETARY ORBITS WEREN'T PERFECT ELLIPSES EITHER. TYCHO'S DATA WAS PERHAPS JUST RIGHT FOR HIM TO ARRIVE AT A FIRM CONCLUSION.

JOHANNES KEPLER 1571-1630

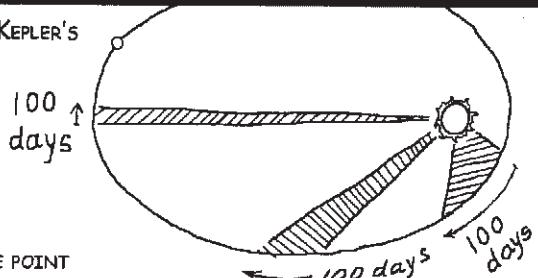


BORN IN GERMANY - A MATHEMATICIAN, ASTRONOMER AND ASTROLOGER; WORLD RENOWNED FOR HIS THREE LAWS GOVERNING PLANETARY MOTION. HE SAW ASTRONOMY AS CELESTIAL PHYSICS AND PLAYED A MAJOR ROLE IN REVIVING THE COPERNICAN WORLD VIEW.

Elliptical Astronomy

WHILE THE FIRST LAW WAS ABOUT THE PATH TRAVESED BY A PLANET, KEPLER'S SECOND LAW TOLD HOW ITS SPEED VARIED.

An imaginary line, connecting a planet to the Sun, sweeps equal areas in equal amounts of time.



ACCORDING TO THIS LAW, IF YOU KNEW THE SPEED OF A PLANET AT ONE POINT ON ITS ORBIT, YOU COULD EASILY FIGURE OUT ITS SPEED AT ALL OTHER LOCATIONS.

IMPRESSIVE AS THE FIRST TWO LAWS WERE, HIS THIRD LAW REALLY TOOK THE CAKE. IT POINTEED OUT AN EXTREMELY SIMPLE RELATIONSHIP EXISTING BETWEEN THE ORBITAL PERIOD OF A PLANET AND ITS ORBITAL SIZE.

The time period T and the size S of a planetary orbit are related in the same way the volume and the area of a sphere are.

Mathematically,
 $T^2 / S^3 = \text{constant}$.

For example, a planet with an orbit that is 4 times larger than another will take 8 times as long to complete its cycle.

THERE WAS A PERFECT MATCH BETWEEN THE AVAILABLE DATA AND KEPLER'S ELLIPTIC MODELS. PTOLEMY HAD INITIATED A STELLAR QUEST. KEPLER FINALLY ARRIVED AT A CONCLUSION. KEPLER'S THEORY MARKED THE END OF ONE JOURNEY AND THE BEGINNING OF ANOTHER.

THE STRIKING THING ABOUT KEPLER'S LAWS WAS THAT THEY APPLIED UNIFORMLY TO ALL PLANETS (EXCLUDING OF COURSE THE MOON). THERE WAS SOMETHING VERY FUNDAMENTAL ABOUT THEM. KEPLER'S LAWS NOT JUST DESCRIBED THE MOVEMENT OF PLANETS BUT THEY CAPTURED THE VERY ESSENCE OF THIS MOTION. A DEEPER STUDY OF KEPLER'S LAWS WOULD CERTAINLY THROW LIGHT ON THE MECHANICS OF THE UNIVERSE?

THIS WAS PRECISELY WHAT HAPPENED. KEPLER'S LAWS AIDED BY GALILEO'S TELESCOPE AND POWERED BY NEWTON'S MATHEMATICAL EQUATIONS INITIATED A NEW ERA OF CELESTIAL PHYSICS.

THE 17TH CENTURY PERHAPS WAS THE MOST EXCITING PERIOD IN THE HISTORY OF ASTRONOMY.

KEPLER HAD BEEN AN ARDENT PROONENT OF THE COPERNICAN PICTURE RIGHT FROM THE VERY BEGINNING. BUT HIS ELLIPTICAL ORBITS DID NOTHING TO REVIVE THE HELIOCENTRIC PICTURE. WHAT TYCHO DID TO THE COPERNICAN THEORY COULD ALSO BE DONE TO KEPLER'S. THE SUN (ALONG WITH ITS PACK OF PLANETS) GOING AROUND THE EARTH WAS CONSISTENT WITH ELLIPTICAL ASTRONOMY.

FORTUNATELY, THE MOON DID NOT OBEY KEPLER'S THIRD LAW. KEPLER'S EXPLANATION WAS THAT IT DID NOT REVOLVE AROUND THE SUN LIKE THE OTHER PLANETS AND HENCE DOESN'T BEHAVE LIKE THEY DO. BUT IF TYCHO'S PICTURE WERE TRUE, THEN WHY DID THE SUN (WHICH REVOLVED AROUND THE EARTH) BEHAVE DIFFERENTLY THAN THE MOON AND SIMILAR TO THE PLANETS REVOLVING AROUND IT? KEPLER HAD A STRONG CASE THERE.

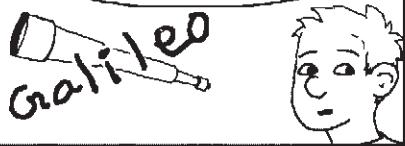
BUT IT TOOK PERSISTENT EFFORT FROM GALILEO FOLLOWED BY THE EMERGENCE OF THE PHYSICAL THEORY BY NEWTON TO PUT THE GEOCENTRIC PICTURE COMPLETELY TO REST.

REGARDLESS OF ALL THIS, THE ELLIPTICAL ASTRONOMY OF KEPLER WAS REGARDED AS THE ASTRONOMY, AND IN EFFECT OVERSHADOWED ALL OTHER THEORIES OF THE PAST.

Galileo

CONTRARY TO POPULAR BELIEF, GALILEO DID NOT INVENT THE TELESCOPE.

Then why is Galileo's name inseparably associated with the telescope?

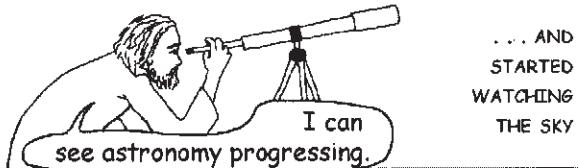


WHEN GALILEO GOT WIND OF A NEW DEVICE THAT MADE DISTANT OBJECTS TO APPEAR CLOSER, HE WASTED NO TIME.



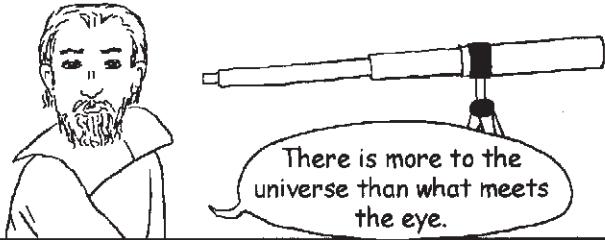
This is it.

HE BROUGHT THE NEW INVENTION HOME, STUDIED IT AND MADE SEVERAL IMPROVEMENTS ...



... AND STARTED WATCHING THE SKY

WHAT THE TELESCOPE REVEALED TO HIM SET ASTRONOMY ON A NEW TRACK.



THE TELESCOPE ACCOMPLISHED TWO THINGS. FIRSTLY ...



The universe is filled with objects we never knew existed before.

SECONDLY, THE ABILITY OF THE TELESCOPE TO REVEAL GREAT DETAIL MEANT ...

... far more accurate observations. Tycho's data will soon become history.



IT IS LIKE COPERNICUS BEING KNOWN FOR THE HELIOCENTRIC THEORY, THOUGH THE IDEA HAD BEEN AROUND FOR MORE THAN A 1000 YEARS. BUT THE CREDIT GOES TO COPERNICUS FOR WORKING THE IDEA INTO A FULL FLEDGED THEORY FOR THE FIRST TIME.

SIMILARLY, GALILEO CHAMPIONED THE USE OF THE TELESCOPE IN ASTRONOMY. HE ALSO SPENT A LIFETIME IMPROVING THE INSTRUMENT.

THROUGH IT, HE SAW A HOST OF CELESTIAL PHENOMENA THAT NO HUMAN BEING HAD SEEN TILL THEN.

GALILEO AND HIS TELESCOPE TOGETHER REVOLUTIONIZED OBSERVATIONAL ASTRONOMY.

GALILEO GALILEI 1564-1642



BORN IN ITALY. HE PIONEERED THE USE OF THE TELESCOPE IN ASTRONOMY. HE DISCOVERED MANY OBJECTS HITHERTO INVISIBLE TO THE NAKED EYE. HE SAW THINGS WHICH NO ONE HAD EVER SEEN BEFORE. GALILEO REVIVED THE COPERNICAN HELIOCENTRIC VIEW OF THE COSMOS. GALILEO'S THEORY WENT AGAINST THE ESTABLISHED DOCTRINE OF THE CHURCH. SO, GALILEO'S LAST YEARS WERE SPENT UNDER HOUSE ARREST.

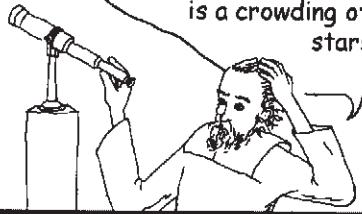
GALILEO PIONEERED THE USE OF QUANTITATIVE EXPERIMENTS. HE ALSO UNDERTOOK A SYSTEMATIC STUDY OF MOTION.

GALILEO HAS BEEN HAILED AS THE FATHER OF MODERN OBSERVATIONAL ASTRONOMY, THE FATHER OF MODERN PHYSICS AND THE FATHER OF SCIENCE.

WHAT KEPLER'S FINDINGS DID TO ASTRONOMY THEORY, GALILEO'S TELESCOPE DID TO OBSERVATIONAL ASTRONOMY.

Galileo's Discoveries

AMONG THE FIRST THINGS GALILEO DISCOVERED IN THE SKY WERE INNUMERABLE STARS TOO FAINT TO BE VISIBLE TO THE NAKED EYE.



Who would have thought! Even the milky way is a crowding of stars.

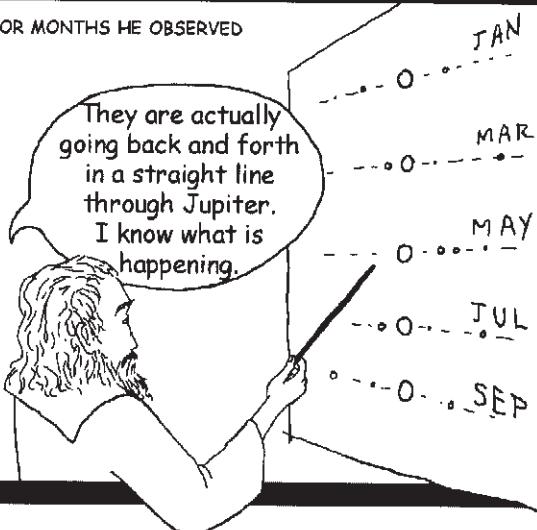
THE TELESCOPE ENLARGED THE PLANETS A BIT. THE STARS APPEARED BRIGHTER BUT STILL RETAINED THEIR POINT LIKE APPEARANCE.



What could this mean? May be the stars are unimaginably far from us. Which kind of explains why we don't see stellar parallax even if the Earth orbits the Sun.

GALILEO, LIKE HIS CONTEMPORARY KEPLER WAS ALSO AN ARDENT ADVOCATE OF THE COPERNICAN THEORY. HIS TELESCOPIC DISCOVERIES HELPED REVIVE THE HELIOCENTRIC THEORY.

HIS MOST EXCITING DISCOVERY WERE THE MOONS OF JUPITER. FOR MONTHS HE OBSERVED WHAT APPEARED LIKE THREE STARS FOLLOWING JUPITER CLOSELY.



SURELY, THERE WAS NOTHING SPECIAL ABOUT EARTH. IT HAD JUST ONE MOON. JUPITER HAD FOUR. THIS FURTHER SUPPORTED THE COPERNICAN HYPOTHESIS.

GALILEO SAW MANY MORE INTERESTING THINGS.

Venus has phases just like the Moon.



Saturn has wings, which appear and disappear.



The moon is not a smooth ball. Its surface is full of bumps and pits.

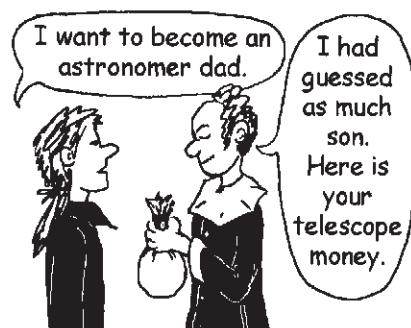


GALILEO'S EXCITING DISCOVERIES GALVANIZED HALF-YAWNING ASTRONOMERS INTO ACTION. THEY WANTED TO SEARCH THE HEAVENS TOO.



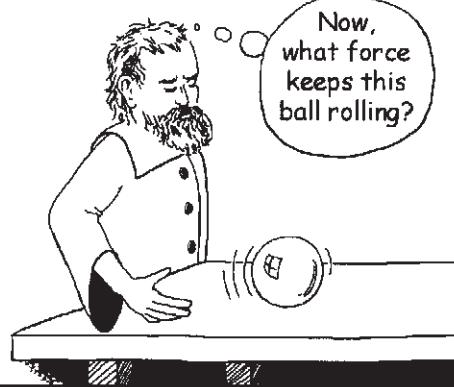
THE TELESCOPE GAINED POPULARITY. IT BECAME INDISPENSABLE FOR OBSERVATIONAL ASTRONOMY.

THE INSTRUMENT HAS EVOLVED OVER THE CENTURIES. BUT IT STILL ENJOYS THE SAME STATUS TODAY AS IT DID IN GALILEO'S TIME.

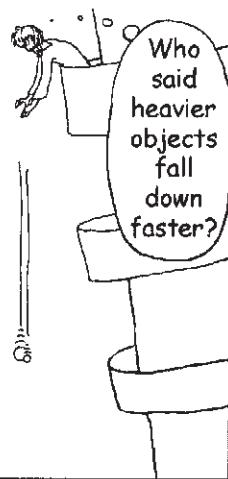


Galilean Physics

A PURELY GEOMETRICAL UNDERSTANDING OF PLANETARY MOTION HAD NOT HELPED TO PROVE THE HELIOCENTRIC THEORY. GALILEO UNDERTOOK A SYSTEMATIC STUDY OF THE PHYSICS OF MOTION.



HE CONDUCTED EXPERIMENTS . . .



. . . AND DREW HIS OWN CONCLUSIONS.

Uniform motion is a natural state of bodies. No external agent (or a force) is needed to keep an object moving uniformly.

The state of rest is only a special case of uniform motion. Inertia which keeps a body at rest also keeps it in motion and prevents it from stopping on its own.

HIS IDEAS WERE QUITE RADICAL.

It is the abruptness of motion-like setting an object (at rest) into motion, or stopping one which is already moving—that requires an external force.

If you are moving uniformly, even at a tremendous speed, you won't feel a thing. However, abruptness in motion is felt immediately.

THIS CAN BE EASILY TESTED BY ANYONE USING AN ELEVATOR.

Why aren't we moving?



GALILEO'S PHYSICAL THEORIES OF MOTION WENT A LONG WAY IN RE-VALIDATING COPERNICUS'S MODEL.

Galileo talks sense, you know.

Yes. And if Galileo is right, then so is Copernicus.

GALILEO FORMED HIS IDEAS ABOUT THE UNIVERSE BASED ON A SOLID FOUNDATION OF OBSERVATION AND LOGIC. HIS THEORY WAS RADICAL AND CONTRADICTED THE EXISTING NOTIONS, ESPECIALLY THOSE FROM THE HOLY SCRIPTURES. THE CHURCH TOOK THIS AS A THREAT.

GALILEO'S IDEAS ON MOTION BECAME THE FOUNDATION UPON WHICH THE THEORY OF PHYSICS BLOSSOMED.

Acceleration is in proportion to the force applied.

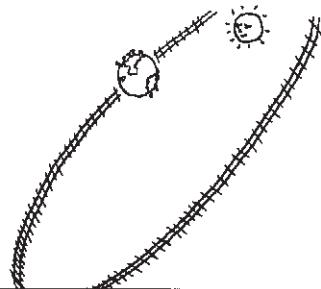
Gravity is indistinguishable from acceleration.

GALILEO WAS IMPRISONED. HIS WRITINGS WERE BANNED. HE SPENT HIS LAST YEARS UNDER HOUSE ARREST.

IT TOOK ALMOST 400 YEARS FOR THE CHURCH TO CATCH UP WITH GALILEO AND WITH SCIENCE. IN 1992, POPE JOHN PAUL II APOLOGIZED ON BEHALF OF THE CHURCH FOR THE WAY THE GALILEO AFFAIR WAS HANDLED. HE ALSO PUBLICLY ACCEPTED THAT EARTH WAS NOT STATIONARY.

Hooke

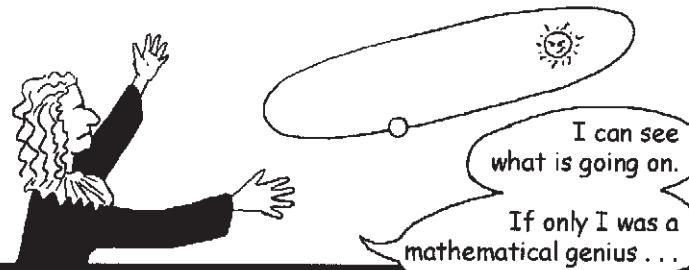
KEPLER HAD URGED THE ASTRONOMERS TO LOOK AT PLANETARY MOTION AS CELESTIAL PHYSICS. GALILEO HAD ARRIVED AT SOME FUNDAMENTAL UNDERSTANDING OF MOTION. BUT WHEN IT CAME TO PLANETARY ORBITS, NOBODY HAD A REAL CLUE.



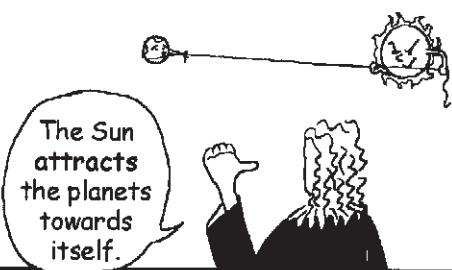
IT WAS ROBERT HOOKE WHO SERVED AS A BRIDGE BETWEEN KEPLER'S MODELS AND NEWTON'S MATHEMATICAL THEORY OF CELESTIAL MECHANICS.



HOOKE EXHIBITED GREAT INTUITION, BUT LACKED THE MATHEMATICAL ABILITY REQUIRED TO SHAPE HIS IDEAS INTO A SCIENTIFIC THEORY.

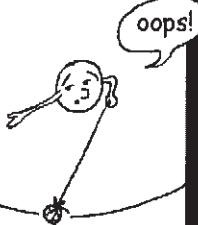


IN FACT, IT WAS HOOKE WHO FIRST RECOGNIZED GRAVITATIONAL ATTRACTION ...

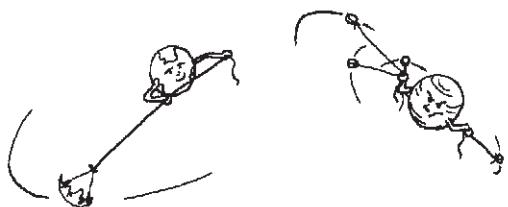


... AND THE ROLE GRAVITY PLAYED IN CELESTIAL MECHANICS

If not for any such force, the planets would have kept moving uniformly in a straight line. Remember what Galileo said?



It is the Sun's attraction that bends these straight paths into elliptical orbits



It is not just the Sun. Every planet attracts its own satellites in the same fashion.



HOOKE ALSO SAID THAT THIS GRAVITATIONAL ATTRACTION WAS STRONGER FOR NEARER OBJECTS AS COMPARED TO THOSE FAR AWAY. THAT IS WHY PLANETS CLOSER TO THE SUN REVOLVED FASTER THAN THOSE WITH LARGER ORBITS.

HOOKE'S IDEAS WERE QUITE APPEALING, ACCEPT THAT THEY WERE IDEAS WITHOUT MATHEMATICAL DETAILS TO SUPPORT THEM. FORTUNATELY, NEWTON, THE MATHEMATICAL GENIUS, HAD ALSO BEEN THINKING ALONG SIMILAR LINES. HE EVENTUALLY WORKED OUT A FULL FLEDGED SCIENTIFIC THEORY, AND BROUGHT CELESTIAL PHYSICS TO A CONCLUSION.

Inverse Square Law

THE CONTRIBUTIONS OF GALILEO AND ROBERT HOOKE WERE PROMISING. BUT THEY DID NOT CONSTITUTE AN UNDERSTANDING OF CELESTIAL MECHANICS. THE FIRE STARTED BY KEPLER'S DISCOVERIES COULD NOT BE PACIFIED WITH QUALITATIVE EXPLANATIONS. THERE WAS A DIRE NEED FOR A PHYSICAL THEORY TO ENUNCIATE KEPLER'S LAWS WITH MATHEMATICAL PRECISION.

THIS CREDIT GOES TO ISAAC NEWTON. HE NOT ONLY WORKED OUT THE MINUTEST DETAILS OF SUCH A THEORY, BUT ALSO INVENTED THE REQUISITE MATHEMATICS.

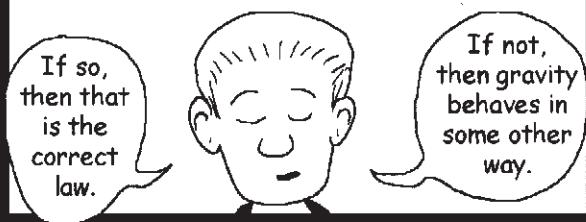
HOOKE INTUITIVELY FELT THAT AS ONE WENT FURTHER AWAY FROM THE SUN ITS GRAVITATIONAL PULL GRADUALLY DIMINISHED. BUT WHAT WAS THE EXACT RELATIONSHIP BETWEEN THE DISTANCE FROM THE SUN AND THE PULL OF GRAVITY? IT WAS STILL A MYSTERY.

EVENTUALLY, GRAVITATION WAS FOUND TO OBEY THE INVERSE SQUARE LAW.

THIS LAW SAYS THAT THE STRENGTH OF THE GRAVITATIONAL PULL DIMINISHES IN PROPORTION TO THE SQUARE OF THE DISTANCE FROM THE SOURCE.



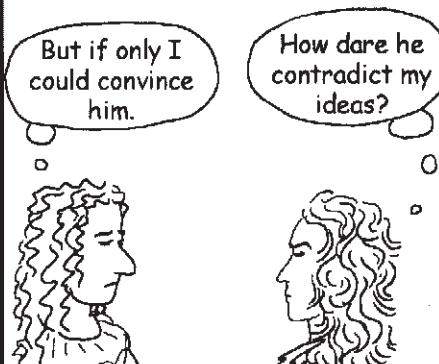
THE REAL QUESTION WAS, 'DOES THE INVERSE SQUARE LAW OF GRAVITATION LEAD TO ELLIPTICAL ORBITS?'



ROBERT HOOKE CLAIMED THAT THE INVERSE SQUARE LAW OF GRAVITY WOULD GIVE RISE TO ELLIPTICAL ORBITS. BUT HE REFUSED TO FURNISH ANY PROOF.

AT LAST HOOKE WENT TO ISAAC NEWTON. BY NOW NEWTON WAS WELL ESTABLISHED AS A REPUTED MATHEMATICIAN. UNFORTUNATELY, THIS MEETING WITNESSED A CLASH OF IDEAS.

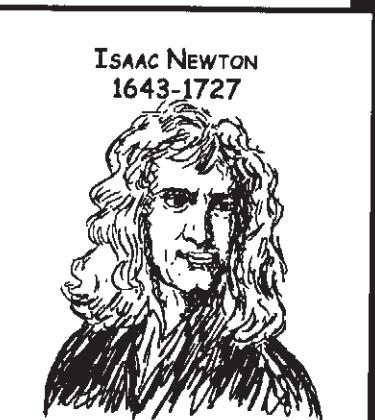
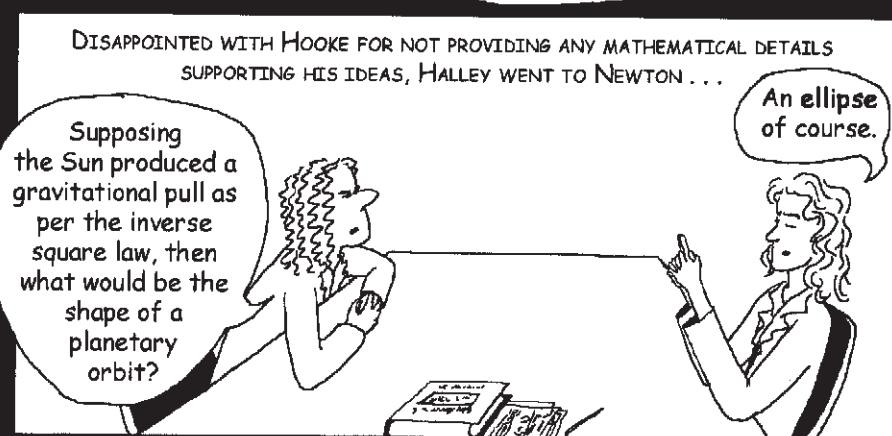
NEWTON WAS DEEPLY OFFENDED. HE RETREATED INTO A SHELL, BUT ONLY TO UNDERTAKE A DEEPER STUDY OF THE MATTER.



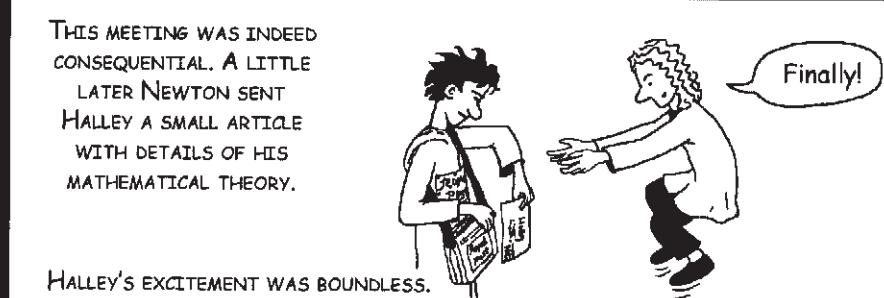
Newton 1642-1727



FORTUNATELY ABOUT THE SAME TIME, EDMOND HALLEY - A YOUNG MEMBER OF THE ROYAL SOCIETY WAS ALSO KEENLY INTERESTED IN A PHYSICAL THEORY OF CELESTIAL MECHANICS.



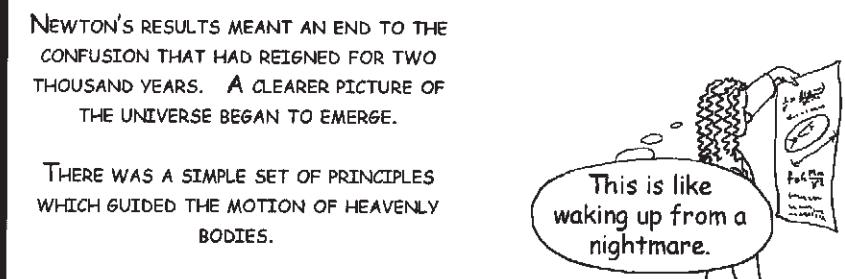
BORN IN ENGLAND. HE INVENTED CALCULUS, PROBABLY HIS GREATEST CONTRIBUTION TO THE WORLD OF SCIENCE. (THE CLAIM FOR INVENTING CALCULUS WAS ALSO SHARED BY LEIBNIZ, RESULTING IN A CONTROVERSY, WHICH WAS NEVER SETTLED.)



HE WORKED OUT A THEORY OF DYNAMICS, GIVING A CONCRETE AND MATURE SHAPE TO PHYSICS. THROUGH THE APPLICATION OF CALCULUS AND DYNAMICS, HE WORKED OUT THE FIRST PHYSICAL THEORY OF ASTRONOMY. HE ALSO STUDIED THE BEHAVIOR OF LIGHT.

NEWTON'S SMALL ARTICLE CONTAINED RESULTS BEYOND HALLEY'S EXPECTATIONS. WITH THE ASSUMPTION OF AN INVERSE SQUARE LAW OF GRAVITATION, NEWTON HAD SHOWED THAT A PLANETARY ORBIT WILL BE ELLIPTICAL (KEPLER'S FIRST LAW), WITH A SPEED VARIATION OBEDIING KEPLER'S SECOND LAW AND AN ORBITAL PERIOD IN ACCORDANCE WITH THE THIRD.

HE INVENTED THE REFLECTING TELESCOPE (ALSO KNOWN AS THE NEWTONIAN TELESCOPE).

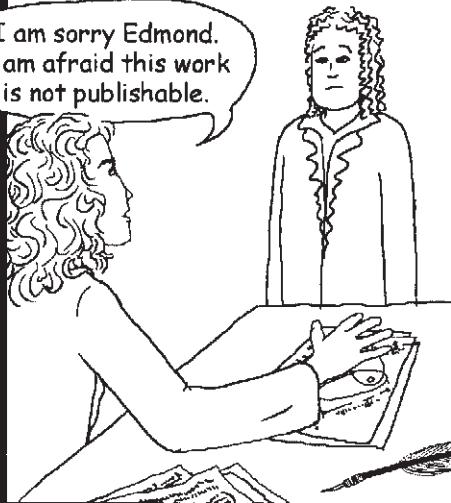


RECOGNIZING THE POTENTIAL OF NEWTON'S WORK, HALLEY COAXED HIM TO PUBLISH THE THEORY.

Principia 1687

NEWTON WAS A PERFECTIONIST. HE WOULD RATHER NOT PUBLISH AT ALL THAN PUBLISH A HALF BAKED ARTICLE AND RISK CRITICISM AND RIDICULE.

I am sorry Edmond. I am afraid this work is not publishable.



ONLY AFTER MUCH COAXING, DID HE RELENT AND SET TO WORK ON A PUBLISHABLE VERSION OF HIS THEORY.

I will see what I can do. This will take some time though.



NEWTON WORKED HARD ON IT FOR THE NEXT THREE YEARS. HE FINALLY CAME UP WITH HIS MASTERPIECE. HIS THEORY WAS TO BECOME THE BIBLE OF PHYSICS FOR THE NEXT TWO HUNDRED YEARS.

Now, THIS certainly is publishable.



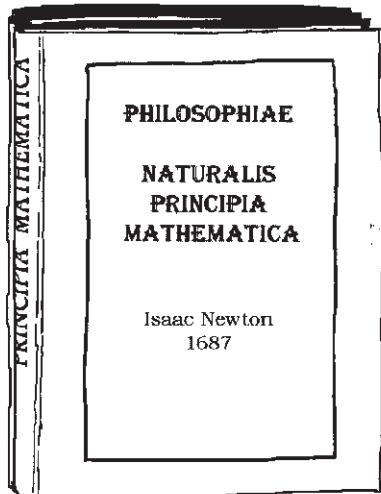
WITHIN THOSE THREE YEARS, NEWTON HAD EXPANDED HIS ORIGINAL NINE-PAGE ARTICLE INTO A SEMINAL WORK AND PUBLISHED IT UNDER THE

IMPRESSIVE TITLE

PHILOSOPHIAE NATURALIS PRINCIPIA
MATHEMATICA

OR

MATHEMATICAL PRINCIPLES OF NATURAL PHILOSOPHY.

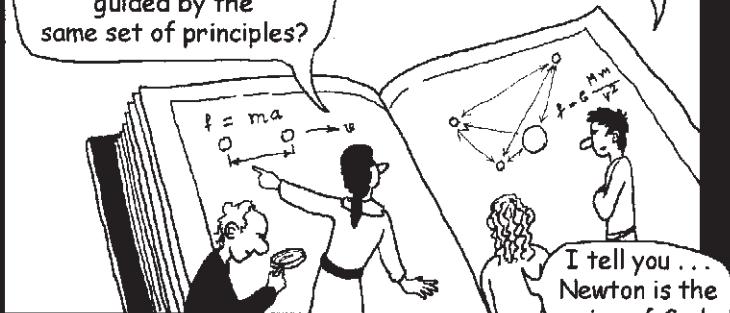


POPULARLY KNOWN BY THE SHORT NAME
PRINCIPIA MATHEMATICA (OR SIMPLY PRINCIPIA)
IT SPANNED THREE VOLUMES.

IN NO TIME, PRINCIPIA BECAME THE GOSPEL,
AND ITS AUTHOR A LEGEND.

Look, how neatly he has laid the foundation for motion. Is every object guided by the same set of principles?

And every planet attracts every other? How fascinating!



I tell you...
Newton is the voice of God.

PRINCIPIA DID THREE THINGS: IT

- A) LAID THE PRINCIPLES GOVERNING THE MOTION OF OBJECTS,
- B) GAVE A PRECISE DESCRIPTION OF HOW EVERY OBJECT ATTRACTED EVERY OTHER OBJECT IN THE UNIVERSE, AND FINALLY,
- C) COMBINED THE TWO TO EXPLAIN WHY THE PLANETS MOVED THE WAY THEY DID.

THE FIRST TWO WERE BRILLIANT YET SIMPLE PIECES OF WORK.

TO EXPLAIN THE MOTION OF PLANETS PRECISELY WAS A COMPLEX MATHEMATICAL TASK. NEWTON ONLY INITIATED IT.

Halley's Comet

RIGHT FROM THE BEGINNING HALLEY HAD TAKEN A KEEN INTEREST IN NEWTON'S WORK. IN FACT IT WAS HALLEY WHO USED HIS PERSONAL FUNDS TO FINANCE THE PUBLICATION OF PRINCIPIA.



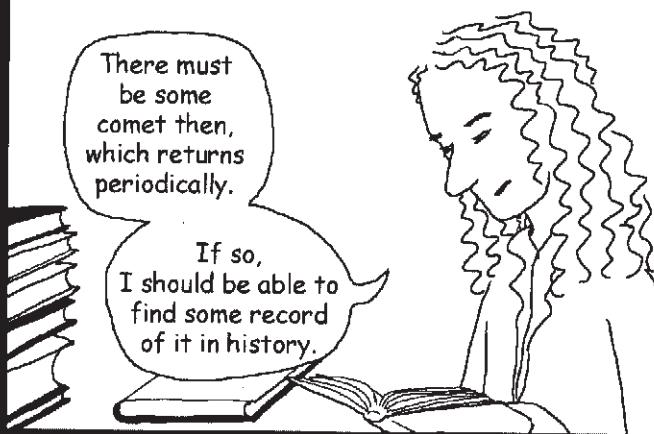
The pleasure is all mine.
And here is your personal copy.

HALLEY PLAYED A PIVOTAL ROLE IN POPULARIZING NEWTON'S THEORY. THIS BROUGHT HIM MUCH FAME.

Rules of universal gravitation must give comets an elliptical orbit too. Then how come we see comets only coming and going?

A comet's path can be elliptical too, but it will be extremely elongated. We just don't get to see the other end of such a long ellipse. And we certainly don't live long enough to witness the return of a comet.

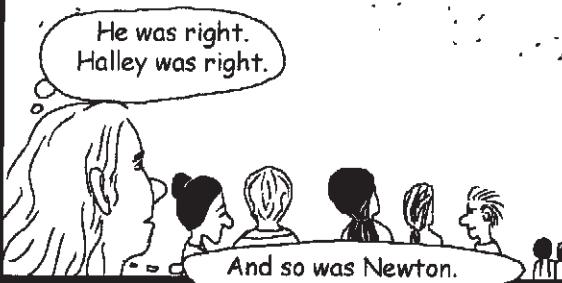
HALLEY, WHO HAD GREAT FAITH IN NEWTON, SET OFF TO VERIFY THIS THEORY.



HE DELVED THROUGH PILES OF HISTORIC DATA. SURELY ENOUGH, HE MANAGED TO IDENTIFY ONE PERIODICAL SEQUENCE OF COMET SIGHTINGS.



A COMET WAS SPOTTED IN 1758 JUST AS HALLEY HAD PREDICTED. IT WAS AN HISTORIC EVENT INDEED. SADLY ENOUGH, HALLEY HAD DIED ALMOST TWO DECADES EARLIER.



THE HALLEY'S COMET CONTINUES TO VISIT THE SUN ONCE EVERY 76 YEARS OR SO, JUST LIKE HALLEY HAD PREDICTED.

EVEN TODAY THE HALLEY'S COMET DRAWS THE ATTENTION OF THE WHOLE WORLD. ITS REAPPEARANCE IS A GREAT CROWD PULLER.

KEEP ON THE LOOK OUT FOR HALLEY'S COMET ON ITS NEXT PREDICTED VISIT SOMETIME AROUND 2061.

Newtonian Physics

THE LAWS OF MOTION PRESENTED IN PRINCIPIA, WERE NOT LIMITED TO CELESTIAL BODIES. THEY APPLIED TO ALL THINGS.

You mean to say I wouldn't be able to walk if the ground doesn't push me forward?

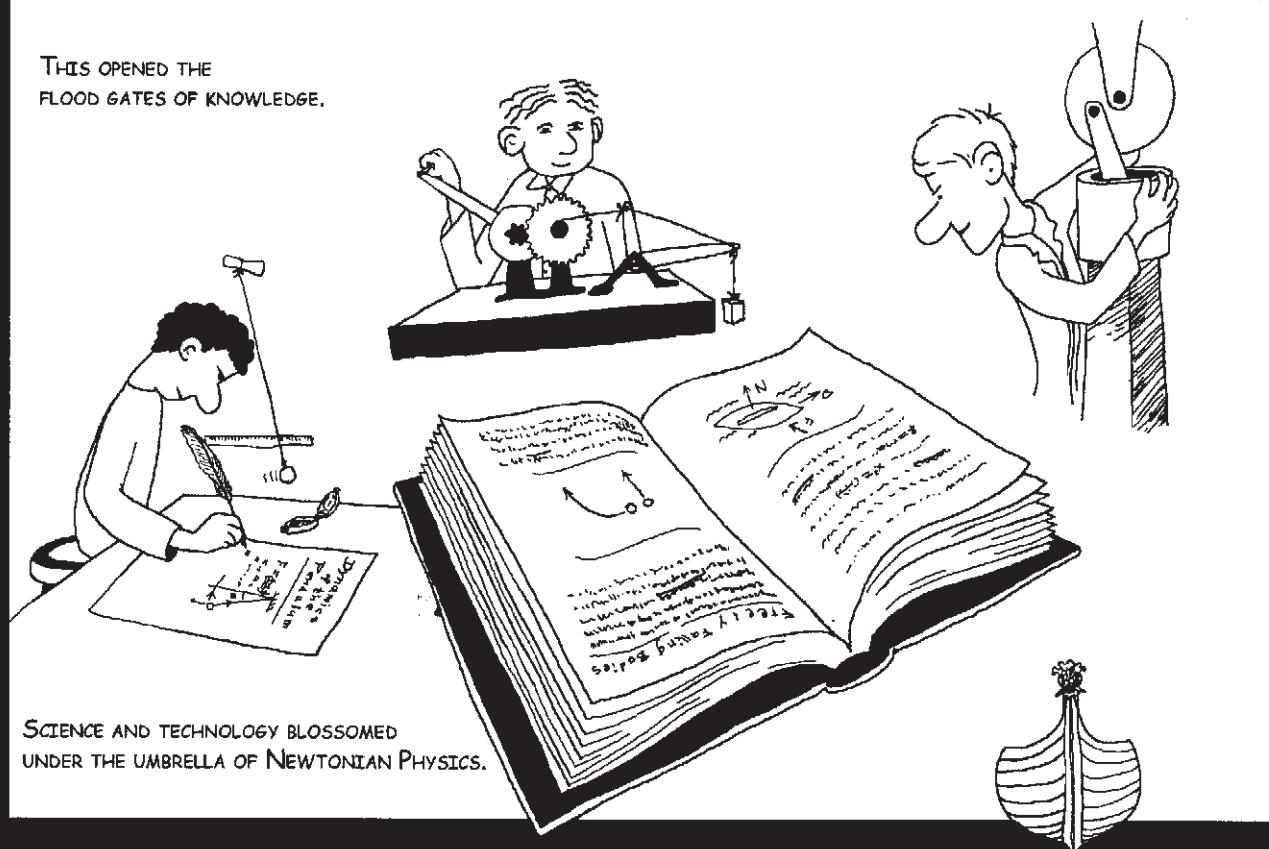
Try walking on ice and then you will know what I mean.

SOON SCIENTISTS STARTED APPLYING NEWTON'S LAWS OF MOTION TO ALL POSSIBLE PHYSICAL PHENOMENA THEY ENCOUNTERED.



MUCH TO THEIR DELIGHT, EVERYTHING THEY INVESTIGATED SEEMED TO FIT WITHIN THE FRAMEWORK DESCRIBED IN PRINCIPIA.

THIS OPENED THE FLOOD GATES OF KNOWLEDGE.



SCIENCE AND TECHNOLOGY BLOSSOMED UNDER THE UMBRELLA OF NEWTONIAN PHYSICS.

NEWTONIAN PHYSICS RULED THE PHYSICAL SCIENCES AND ENGINEERING FOR TWO HUNDRED YEARS.

NEWTON SEEMED TO HAVE REVEALED THE SECRETS OF NATURE.

PEOPLE STARTED REPOSING THEIR FAITH IN SCIENTIFIC ENQUIRY.

SCIENCE AND TECHNOLOGY WOULD HENCEFORTH POWER THE ENGINES OF GROWTH.

The Mystery of the Missing Planet

SOME PEOPLE FOUND A STRIKING VOID IN THE SOLAR SYSTEM. THERE WAS A HUGE GAP BETWEEN THE FOUR INNER PLANETS AND THE TWO OUTER PLANETS. HOW DOES ONE EXPLAIN THIS ANOMALY?

Maybe there's a little planet inside Jupiter's orbit which has escaped our telescopes.

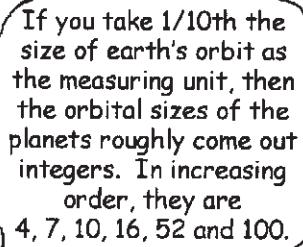


The creator is wise. Since the outer planets are rather large, they could easily disturb the orbits of small planets if they were close by.



SOME PEOPLE THOUGHT THAT THE ORBITAL SIZES OF PLANETS FOLLOWED A SEQUENCE.

If you take 1/10th the size of earth's orbit as the measuring unit, then the orbital sizes of the planets roughly come out integers. In increasing order, they are 4, 7, 10, 16, 52 and 100.



How interesting! And if you subtract 4 from each integer in this sequence and divide it by three, you will get a new sequence: 0, 1, 2, 4, 16, 32

SUCH A STRIKINGLY SIMPLE SEQUENCE COULD HARDLY BE A COINCIDENCE. ASTRONOMERS STRONGLY BELIEVED THAT THE SEQUENCE WAS A LAW FOLLOWED BY THE ORBITAL SIZES OF THE PLANETS-EXCEPT FOR THE MISSING NUMBER 8.

What do you mean by the missing number? We haven't spotted the planet. That is all.



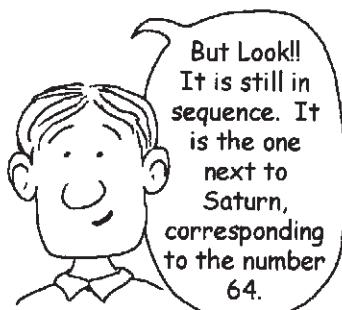
The question is who finds it first.



IN 1781, WILLIAM HERSCHEL, AN AMATEUR ASTRONOMER, DISCOVERED A NEW PLANET. IT WAS NAMED URANUS. INTERESTINGLY, ITS ORBIT DID NOT LIE WITHIN THAT OF JUPITER WHERE THE SEARCH FOR THE MISSING PLANET WAS ON, BUT WELL BEYOND THAT OF SATURN.



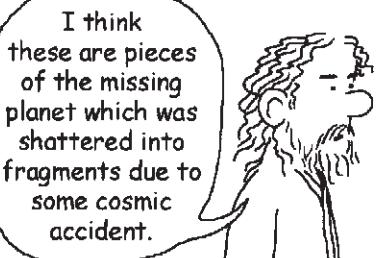
So what if it is not the missing one?
But Look!! It is still in sequence. It is the one next to Saturn, corresponding to the number 64.



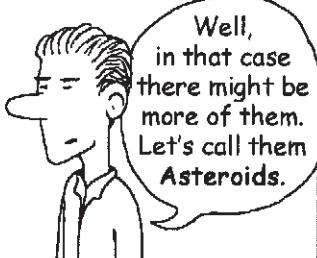
THE FACT THAT THE NEWLY FOUND PLANET URANUS HAD AN ORBITAL SIZE THAT FITTED THE LAW WAS VERY ENCOURAGING. THIS, IF ANYTHING, RESULTED IN INTENSIFYING THE SEARCH FOR THE MISSING PLANET CORRESPONDING TO NUMBER 8.

IN 1801, AN ITALIAN ASTRONOMER CALLED GIUSEPPE PIAZZI SPOTTED A TINY OBJECT MOVING IN THE REGION OF THE MISSING PLANET. THREE MORE TINY OBJECTS WERE FOUND IN THE SAME REGION WITHIN THE NEXT FEW YEARS.

I think these are pieces of the missing planet which was shattered into fragments due to some cosmic accident.



Well, in that case there might be more of them. Let's call them Asteroids.



By 1891 MORE THAN 300 ASTEROIDS HAD BEEN FOUND. ALL ORBITED THE SUN IN THE REGION OF THE MISSING PLANET - WHICH CORRESPONDED TO THE NUMBER 8 IN THE SEQUENCE.

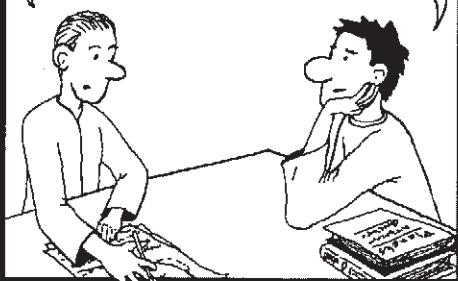
EVEN TODAY, NOBODY REALLY KNOWS HOW THE ASTEROIDS ORIGINATED. ACCORDING TO A WIDELY ACCEPTED THEORY THE DISRUPTIVE PULL OF JUPITER PREVENTED THESE FRAGMENTS FROM FORMING A PLANET.

Triumph Of Newtonian Physics

THE MOVEMENT OF URANUS WAS PUZZLING.

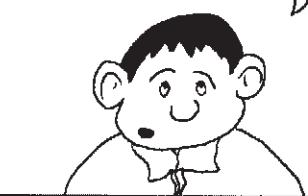
I have taken everything into consideration. Yet Uranus keeps deviating from the predicted path.

Maybe Newton's laws are not valid for such large distances.



INDEED, ONE COULD QUESTION THE VALIDITY OF NEWTON'S THEORY AT THE EDGE OF THE SOLAR SYSTEM, OR . . .

Perhaps we haven't considered everything that needs to be considered. Maybe there is another planet we haven't yet seen which keeps pulling Uranus out of its course.



IN 1840, TWO BRIGHT MATHEMATICIANS, JAMES AND JONES SET TO WORK INDEPENDENTLY.

Let us suppose there is an unseen object that is pulling Uranus out of its track.



UNDER THE ASSUMPTION THAT NEWTON'S THEORY WAS CORRECT, THE TWO MATHEMATICIANS DID CALCULATIONS AND ARRIVED AT A FIRM CONCLUSION.

There has to be a planet right about here.

Hope the guys with the telescopes manage to spot it.



IN 1846, A NEW PLANET TRaversing an orbit was spotted, exactly as predicted by JOHN AND JAMES.

This is so exciting. I won't doubt Newtonian physics ever again.



THE DISCOVERY OF NEPTUNE (AS THE NEWLY DISCOVERED PLANET WAS CALLED) MARKED THE HIGHEST ACHIEVEMENT OF NEWTONIAN PHYSICS.

Great! A pair of mathematicians, just sitting at their desks could predict the location of an unseen planet with pinpoint accuracy!



DRAMATIC AS THE PREDICTION AND DISCOVERY OF NEPTUNE WAS, ITS EXISTENCE DID NOT ACCOUNT FOR THE DEVIATION OF URANUS'S PATH COMPLETELY. A SMALL DISCREPANCY LEFT UNEXPLAINED WAS ATTRIBUTED TO YET ANOTHER UNSEEN PLANET. NATURALLY, ASTRONOMERS TRIED TO PREDICT THE LOCATION OF THIS 9TH PLANET OF THE SOLAR SYSTEM. IN 1930, A TINY BODY (ONE FIFTH THE SIZE OF OUR MOON) WAS LOCATED ROUGHLY WHERE THE PREDICTIONS POINTED OUT. IT WAS NAMED PLUTO.

TODAY WE KNOW THAT PLUTO IS TOO TINY TO CAUSE ANY NOTICEABLE DEVIATION IN THE PATH OF URANUS. THE DISCREPANCY BETWEEN ITS PREDICTED AND OBSERVED PATHS WAS DUE TO INCORRECT ESTIMATION OF NEPTUNE'S MASS. BY AN AMAZING COINCIDENCE, PLUTO WAS FOUND WHERE A MISCALCULATION PREDICTED IT TO BE.

IN 2006, PLUTO WAS NO MORE CONSIDERED A PLANET BUT ONE OF MANY DWARF PLANETS ORBITING THE SUN BEYOND NEPTUNE.

Beyond Newton

NEWTON'S PHYSICS THRIVED FOR A GOOD 200 YEARS.

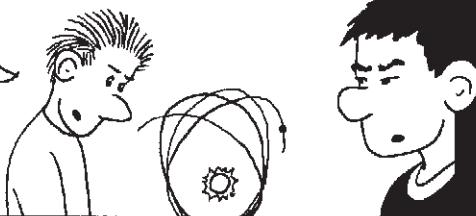
It is nothing compared to the 1500 years of supremacy enjoyed by Ptolemy, but during these 200 years, Newton's theory has covered most of the physical phenomena known to humankind.



AFTER NEPTUNE'S DISCOVERY ANOTHER UNUSUAL THING CAUGHT THE ATTENTION OF ASTRONOMERS. IT WAS THE ORBIT OF MERCURY.

See how Mercury's orbit keeps turning? This can't be explained by the combined pull of all the other known planets.

Are you suggesting that there is another planet like Neptune yet undiscovered?



SOME PEOPLE THOUGHT THAT THERE WAS A PLANET WITH A TINY ORBIT WHICH EVADED SIGHTING BECAUSE OF THE SUN'S GLARE.

THE FICTITIOUS PLANET WAS NAMED VULCAN.

I swear I saw Vulcan yesterday. Don't know where it's hiding now.



NUMEROUS FALSE SIGHTINGS OF VULCAN WERE REPORTED, BUT NEVER PROVED.

IN 1915 THE FAMOUS GERMAN PHYSICIST ALBERT EINSTEIN CAME UP WITH A NEW THEORY OF GRAVITATION CALLED THE GENERAL THEORY OF RELATIVITY. IT WAS A COMPLETELY NEW WAY OF LOOKING AT GRAVITY. ACCORDING TO EINSTEIN'S THEORY, NEWTONIAN THEORY OF CELESTIAL MECHANICS WAS ONLY APPROXIMATELY CORRECT.

Wait a minute. According to Einstein, all elliptical orbits precess like that of Mercury.



Mercury's precession matches with Einstein's theory perfectly. I have gone through the calculations myself.

EINSTEIN'S GENERAL THEORY OF RELATIVITY ELIMINATED THE NEED TO LOOK FOR ANOTHER PLANET. VULCAN REMAINED FICTITIOUS.

Newton's theory failed here. Thanks to Einstein, we were saved in time.

It would have been cool to have a new planet though. I kind of liked the name Vulcan.



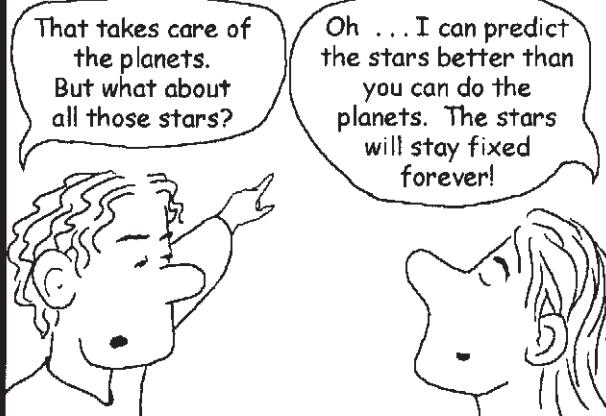
THAT NEWTON'S THEORY WAS ONLY APPROXIMATE WAS HARD TO SWALLOW, BUT THE EVIDENCE WAS COMPELLING. MOREOVER EINSTEIN'S THEORY WAS RADICALLY BEAUTIFUL. ACCORDING TO EINSTEIN, SPACE AND TIME WERE INTERWOVEN INTO A FABRIC. HE SAID THAT GRAVITY WAS NOT A FORCE AT ALL BUT A FORCE-LIKE ILLUSION CAUSED BY THE SPACE-TIME FABRIC WHICH BENT PATHS OF FREELY MOVING OBJECTS.

EINSTEIN ARGUED THAT THE SPACE-TIME FABRIC THAT BENDS PATHS OF OBJECTS ALSO BENDS THE PATH OF LIGHT. THIS PHENOMENON KNOWN AS GRAVITATIONAL LENSING WAS CAREFULLY MEASURED AND IT MATCHED WELL WITH EINSTEIN'S CALCULATIONS. THE GENERAL THEORY OF RELATIVITY WAS SLOWLY ACCEPTED AS A SUPERIOR THEORY FOR UNDERSTANDING CELESTIAL MECHANICS.

EINSTEIN'S THEORY OF GRAVITATION HAS STOOD ITS GROUND FOR ALMOST A CENTURY. IT IS STILL THE BEST THEORY AVAILABLE TO EXPLAIN CELESTIAL MOTION.

What About The Stars?

KEPLER HAD FIGURED OUT THE FUNDAMENTAL NATURE OF CELESTIAL MOTION. NEWTON'S BRILLIANT MATHEMATICS REVEALED ITS PHYSICAL MECHANISM.



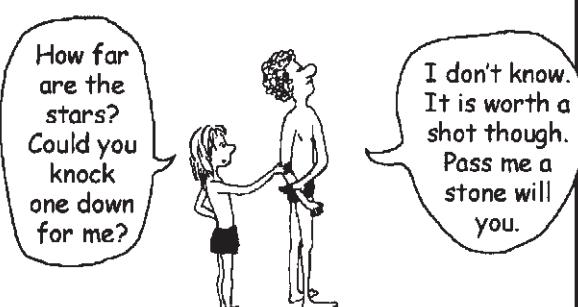
SINCE THE VERY BEGINNING OF THE HISTORY OF ASTRONOMY, TWO IDEAS HADN'T CHANGED MUCH . . .



THE FIXED PATTERN OF STARS WAS THE FOUNDATION UPON WHICH THE ENTIRE STUDY OF PLANETS WAS BASED. BUT THE STARS THEMSELVES FAILED TO INTRIGUE THE HUMAN MIND.

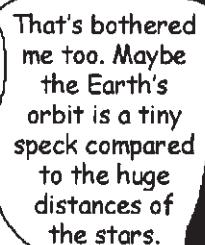
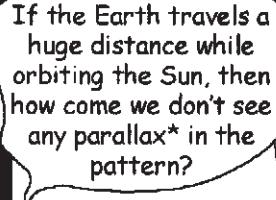
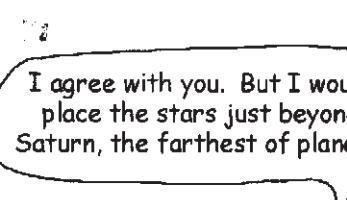
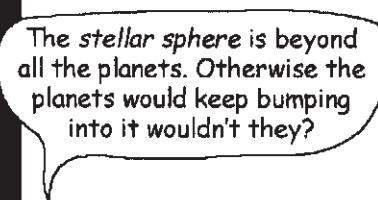


HOW FAR AWAY WERE THE STARS FROM THE EARTH? THIS WAS THE MOST NATURAL QUESTION TO ASK. BUT NO ONE REALLY HAD A CLUE.



THERE WAS NO OBSERVATIONAL EVIDENCE THAT COULD HAVE GIVEN AWAY THE DISTANCE OF THE STARS FROM THE EARTH. ASTRONOMERS MADE THEIR OWN GUESSES. ALMOST ANYTHING WENT.

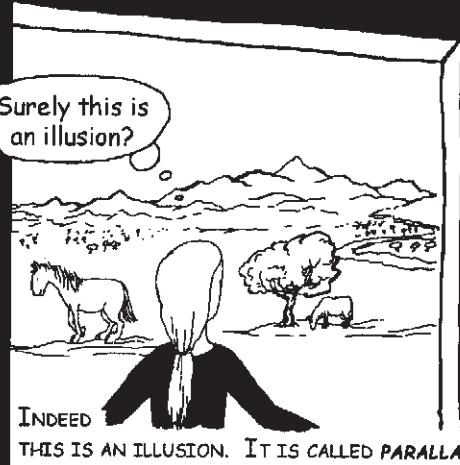
THE STRONGEST HINT CAME FROM THE HELIOCENTRIC THEORY OF COPERNICUS.



* WHAT IS PARALLAX?

What Is Parallax?

HAVE YOU EVER NOTICED THE SCENERY THROUGH THE WINDOW SHIFTING AS YOU MOVE YOUR HEAD?



INDEED THIS IS AN ILLUSION. IT IS CALLED PARALLAX.

PARALLAX IS REALLY ABOUT NEARBY AND FARAWAY OBJECTS. AS YOU CHANGE YOUR VIEWING LOCATION, THE THINGS IN VIEW SEEM TO CHANGE THEIR RELATIVE POSITIONS TOO. THIS CHANGE DEPENDS UPON THEIR DISTANCE FROM YOU.

Yes.
The hilltop, the tree and the horse all seem to come closer or move apart when I shift my head sideways.

But the tree and the cow grazing right under it, move together.



EVEN OUR TWO EYES SEE DIFFERENT IMAGES BECAUSE THEY LOOK AT THE WORLD FROM TWO DIFFERENT LOCATIONS.

What happens if I look at a scene with only one eye and then with the other?



NOT SURPRISINGLY, SWITCHING BETWEEN EYES GIVES AN EFFECT SIMILAR TO THAT RESULTING FROM MOVING YOUR HEAD FROM SIDE-TO-SIDE.

PARALLAX IS VERY USEFUL. THE EXTENT TO WHICH THE RELATIVE POSITIONS OF OBJECTS SHIFT ALSO GIVES US AN IDEA ABOUT THEIR DISTANCES FROM US.

Can you tell distances using parallax?



Of course I can. And so can you. In fact we are all experts at it.

Close one eye and then try to touch my fingertip with yours. Now try the same thing with both your eyes open.

POSITION YOUR TWO THUMBS IN FRONT OF YOUR FACE, ONE CLOSE TO IT AND THE OTHER FARTHER AWAY. NOW ALTERNATE BETWEEN YOUR EYES.

See how my left thumb is on the left of my right thumb when I see with the left eye?

But it shifts to the right of the right thumb the moment I switch to the right eye.



This parallax thing is damn confusing.

but useful nevertheless.

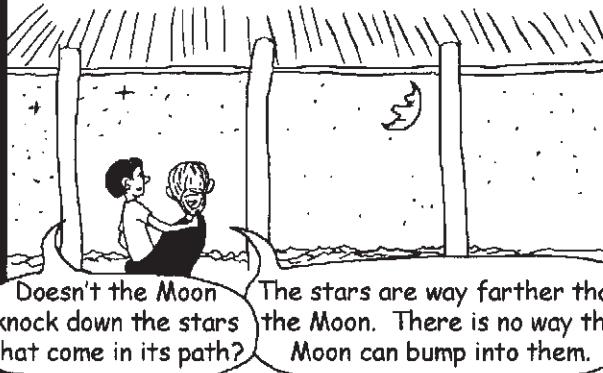
THE IMAGES FROM OUR TWO EYES ARE PROCESSED BY OUR BRAIN TO TELL US THE DISTANCES OF OBJECTS. THIS COMBINING OF TWO IMAGES, CALLED STEREO VISION, GIVES US A THREE DIMENSIONAL VIEW OF THE WORLD.



FOCUS ON A POINT IN BETWEEN THE TWO WINDOWS ABOVE. NOW SLOWLY MOVE THE POINT OF FOCUS AWAY FROM YOU INTO THE PAPER TILL YOU SEE EXACTLY THREE WINDOWS. WHAT DO YOU SEE IN THE MIDDLE ONE?

Annual Parallax

OUR STEREO VISION IS QUITE GOOD FOR ESTIMATING DISTANCES OF NEARBY OBJECTS BUT IT FAILS TO CORRECTLY PLACE OBJECTS BEYOND A KILOMETER OR SO.



OBJECTS MORE THAN A KILOMETER AWAY APPEAR ALMOST THE SAME TO BOTH EYES.

WE CAN ONLY INFER THAT THOSE OBJECTS MUST BE VERY FAR AWAY.

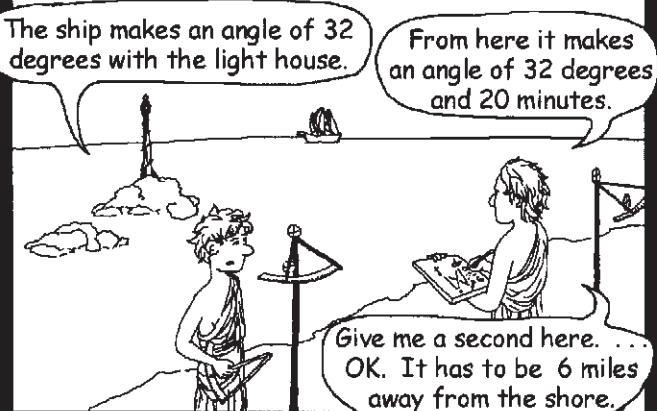
OUR STEREO VISION CAN NOT HELP US IN ESTIMATING THE DISTANCES OF HEAVENLY BODIES.

THE ANCIENT GREEKS, HAVING MASTERED GEOMETRY, HAD FIGURED OUT HOW TO MEASURE FAR AWAY DISTANCES USING PARALLAX.

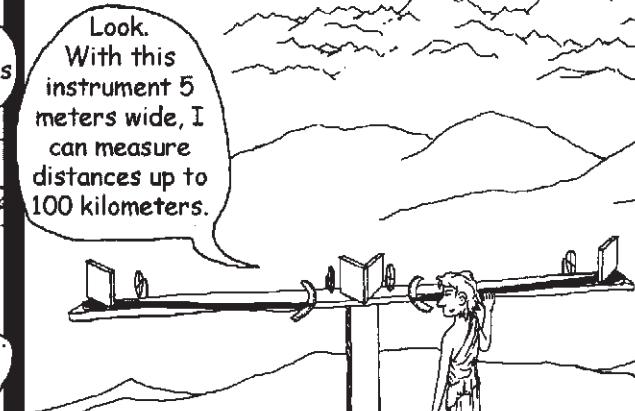
It is not so elegant as stereo vision, but still very effective.



THEY VIEWED A SCENE FROM TWO POINTS WITH A SEPARATION MUCH LARGER THAN THAT BETWEEN OUR TWO EYES. BY COMPARING THESE IMAGES THEY COULD ESTIMATE DISTANCES OF OBJECTS BEYOND THE RANGE OF STEREO VISION.



THE WIDER THE SEPARATION BETWEEN TWO VIEWING LOCATIONS, THE FARTHER THE DISTANCE THAT COULD BE MEASURED.

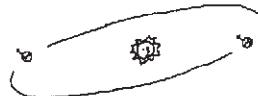


TO MEASURE ASTRONOMICAL DISTANCES USING PARALLAX, ONE HAS TO CHOOSE TWO VIEWING LOCATIONS THAT ARE THOUSANDS OF KILOMETERS APART.

Compare two observations - one made late at dusk, the other at early dawn. Earth's rotation will have carried you across thousands of kilometers through the night.



That's a terrific idea. Now, how about comparing observations that are six months apart? We will have traversed half the orbit around the Sun.



THIS IS CALLED ANNUAL PARALLAX. IN THE EARLY DAYS, WHEN THE SIZE OF EARTH'S ORBIT WAS STILL NOT KNOWN, ANNUAL PARALLAX COULD YIELD ONLY RELATIVE DISTANCES.

According to my calculation, Saturn has an orbit 9 times larger than that of the Earth. How large exactly is that?

18 AU of course. And did you catch any stellar parallax yet?

AS WE KNOW NOW, EVEN THE EARTH'S ORBIT IS NOT LARGE ENOUGH TO OBSERVE STELLAR PARALLAX EASILY. THE STARS WERE SIMPLY TOO FAR. BUT THE SEARCH WENT ON.

Stellar Activity

IN THE END IT WAS A STRANGE STELLAR ACTIVITY WHICH DREW THE ATTENTION OF ASTRONOMERS TO THE STARS.

What a bright star.
I could swear it
was not there
yesterday.

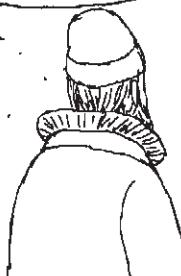


But I thought the
stellar sphere
never changed.



A BRIGHT STAR WAS SPOTTED BY TYCHO IN 1572. IT WAS CALLED NOVA, MEANING NEW STAR.

Hey ... Where did
that Nova go?



Looks like it went
the way it came.



MORE NOVAE (PLURAL OF NOVA) WERE SPOTTED OVER THE COMING DECADES. MANY DISAPPEARED WITHIN A FEW DAYS. SOME KEPT DISAPPEARING AND REAPPEARING.

THIS STELLAR PHENOMENON DREW THE ATTENTION OF ASTRONOMERS. THE NEWLY INVENTED TELESCOPE MADE A BIG DIFFERENCE.

This is something.
The stars keep
varying in
brightness.



At least
some of
them do.

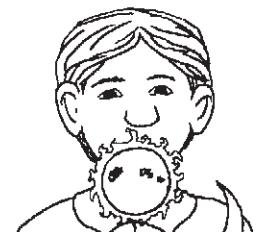
HOW DID THE ASTRONOMERS MISS ALL THIS STELLAR ACTIVITY UNTIL NOW? FOR ONE, NONE OF THE BRIGHT STARS VARIED. SO BEFORE THE TELESCOPE, THE CHANGE IN BRIGHTNESS OF STARS WAS DIFFICULT TO NOTICE. IT WAS ALSO ASSUMED SINCE THE DAYS OF PTOLEMY THAT THE SPHERE OF STARS WAS UNCHANGEABLE. WHY SPEND TIME GAZING AT THE IMMUTABLE STARS? WELL, THE NOVA CHANGED IT ALL. NOW THE ASTRONOMERS WERE BACK STUDYING THE STARS.

AND ONCE SCIENTISTS STARTED LOOKING FOR STELLAR ACTIVITY, THEY SOON FOUND IT IN ABUNDANCE. THE UNIVERSE WAS FULL OF VARIABLE STARS.

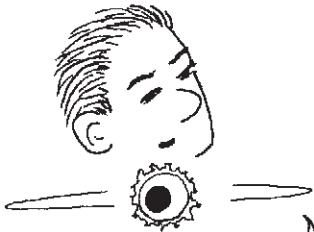
SOME STARS VARIED ERRATICALLY WHILE SOME SHOWED PERIODIC VARIATIONS. SOMETHING WAS GOING ON. THIS STELLAR ACTIVITY EXCITED THE SCIENTIFIC COMMUNITY. LOTS OF ASTRONOMERS CAME UP WITH POSSIBLE EXPLANATIONS.



The stars
are like the Sun,
only far away.



And
some kind of
sun-spots cause
the stars to
appear dimmer at
times?



May be
some stars have planets
orbiting them and get
eclipsed periodically.



I have spotted two
stars orbiting each
other, that too in
elliptical orbits.

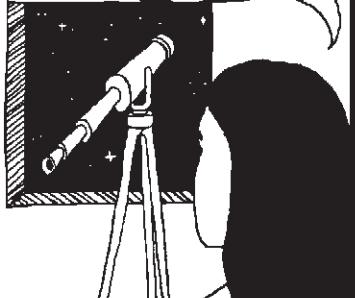
That Is Really Far

OBSERVING STELLAR PARALLAX WAS AS HOPELESS AS EVER. IN THE MEANWHILE, OTHER DEVELOPMENTS OCCURRED.

Nothing like parallax when it comes to measuring distance.



No doubt. But life has to move on. There are other things in the universe you know.



IN MID 1650, THE DUTCH PHYSICIST CHRISTIAAN HUYGENS ESTIMATED THE DISTANCE BETWEEN SIRIUS AND EARTH.

Assuming that the star Sirius is no different than the Sun, how far does it have to be in order to appear as bright as it does?



30,000 times farther than the Sun, I guess. Now, that is hard to imagine.

HUYGENS' ASSUMPTION WAS BASELESS, AND HIS METHODOLOGY CRUDE. ASTRONOMERS DIDN'T EVEN KNOW HOW FAR THE SUN WAS. BUT HIS ESTIMATE HELPED PEOPLE TO BEGIN APPRECIATING THE VASTNESS OF THE UNIVERSE.

BASED ON SIMILAR ASSUMPTIONS, NEWTON TOO HAD ESTIMATED THE DISTANCE OF SIRIUS.

If my calculations are correct, Sirius is a million times farther than the Sun.



That is mind boggling.

ONLY NEWTON'S SMALL COTERIE OF FRIENDS KNEW THIS ESTIMATE. THEY WERE AMAZED.

IN 1671, GIOVANNI CASSINI, AN ITALIAN-FRENCH ASTRONOMER, FIGURED OUT THE DISTANCE BETWEEN EARTH AND THE PLANET MARS.

You know what this means? Now we can compute all the distances in the Solar System.



Because we already know the relationship between these distances?



The Sun is 150,000,000 kilometers from us? Get out of here.



And guess how wide the orbit of Saturn is. More than 2,000,000,000 km.



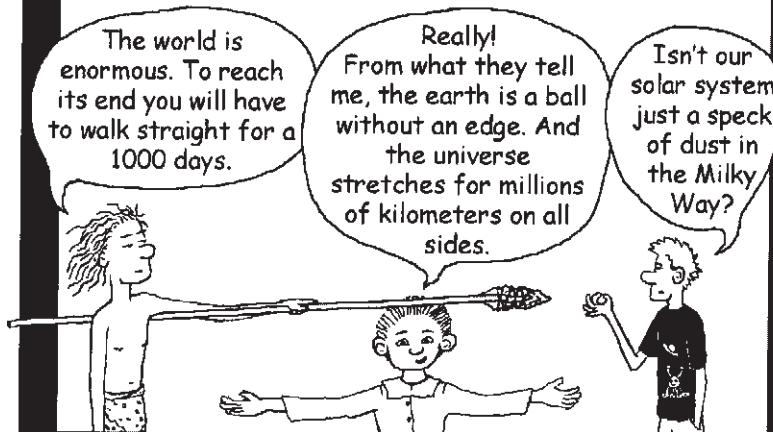
150 MILLION KM! 2 BILLION KM!! THESE DISTANCES WERE SIMPLY MIND BOGGLING.

IF OUR SUN AND ITS PLANETS - THE SOLAR SYSTEM ITSELF WAS SO HUGE, HOW LARGE THEN WAS THE SPHERE OF STARS? NEWTON ESTIMATED THE 'STAR SPHERE' TO BE A STAGGERING 2,000,000,000,000,000 KM.

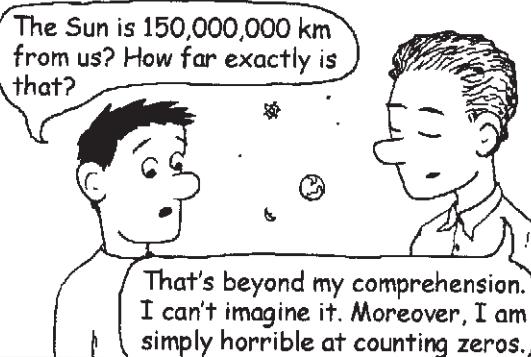
WERE ALL STARS ACTUALLY FIXED TO A SPHERE AS ASSUMED? OR WERE THEY ALL SCATTERED AT DIFFERENT DISTANCES FROM US ACCORDING TO THEIR RANGE OF BRIGHTNESS? IN THAT CASE, HOW LARGE WOULD THE UNIVERSE BE?

Astronomical Unit

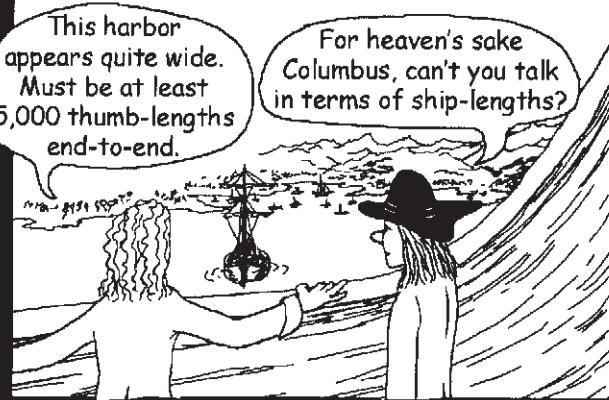
THE WORLD WAS VAST, EVERYONE AGREED. BUT HOW LARGE WAS IT? THROUGHOUT HISTORY PEOPLE HAVE HAD DIFFERENT BELIEFS.



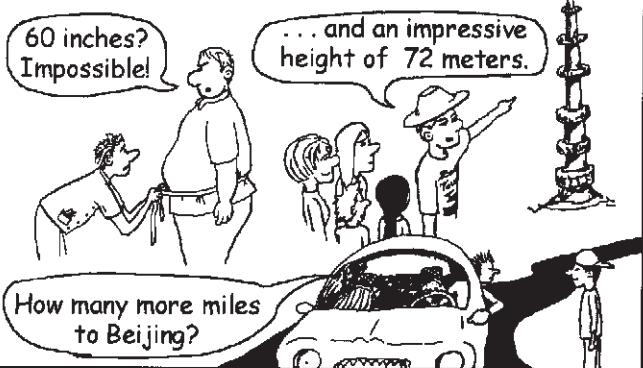
MANY TIMES IN HISTORY, PEOPLE CAME TO THE CONCLUSION THAT THE UNIVERSE WAS MUCH LARGER THAN WHAT IT WAS BELIEVED TO BE. AND EVERY TIME IT CHALLENGED THEIR IMAGINATION.



LIKE ALL PHYSICAL QUANTITIES, DISTANCES COULD ONLY BE EXPRESSED WITH REFERENCE TO A STANDARD. USUALLY A KNOWN DISTANCE - A UNIT IS USED TO QUANTIFY OTHER DISTANCES.

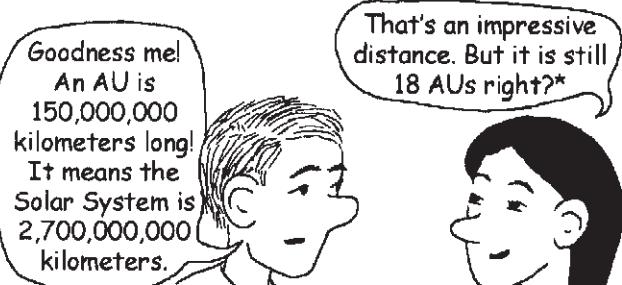


DEPENDING ON THE SITUATION, SOME UNITS FITTED MORE NATURALLY THAN OTHERS.



WHEN THE SOLAR SYSTEM WAS UNDER ANALYSIS, THE DISTANCE BETWEEN THE SUN AND THE EARTH WAS TAKEN AS THE UNIT NATURAL FOR EXPRESSING THE DISTANCES INVOLVED. THIS DISTANCE WAS CALLED THE ASTRONOMICAL UNIT WRITTEN AU FOR SHORT.

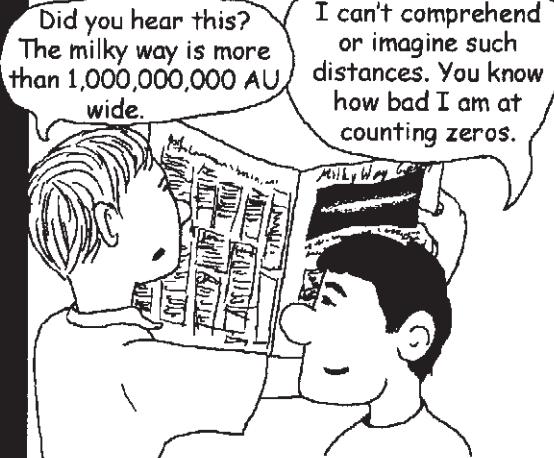
INTERESTINGLY, WHEN IT CAME INTO USE, THE SIZE OF THE ASTRONOMICAL UNIT ITSELF WAS UNKNOWN. BUT SINCE THE RATIOS OF DISTANCES IN THE SOLAR SYSTEM HAD BEEN FIGURED OUT, THE AU SERVED ITS PURPOSE. LATER IN 1672, THE ACTUAL VALUE OF AU WAS ESTIMATED IN MILES. EVER SINCE THE AU HAS CONTINUED TO BE THE NATURAL UNIT ASSOCIATED WITH THE SOLAR SYSTEM.



* IN THE 17TH CENTURY, THE SOLAR SYSTEM ENDED AT SATURN.

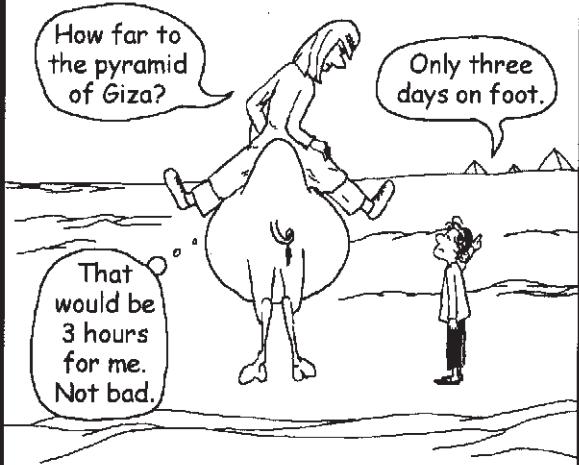
Light Year

THE AU DID GREAT AS A NATURAL UNIT FOR INTERPLANETARY DISTANCES. BUT WAS IT GOOD ENOUGH FOR THE STELLAR WORLD?



THERE WAS AN URGENT NEED FOR A NEW UNIT FOR EXPRESSING THE DISTANCES OF FAR AWAY STARS.
WHAT WOULD IT BE?

HUMAN BEINGS ARE TRAVELLERS AT HEART. RIGHT FROM OUR NOMADIC DAYS WE HAVE EQUATED DISTANCE TO TRAVEL TIME.



THE USE OF TRAVEL TIME TO EXPRESS DISTANCE IS STILL VERY MUCH IN FASHION.



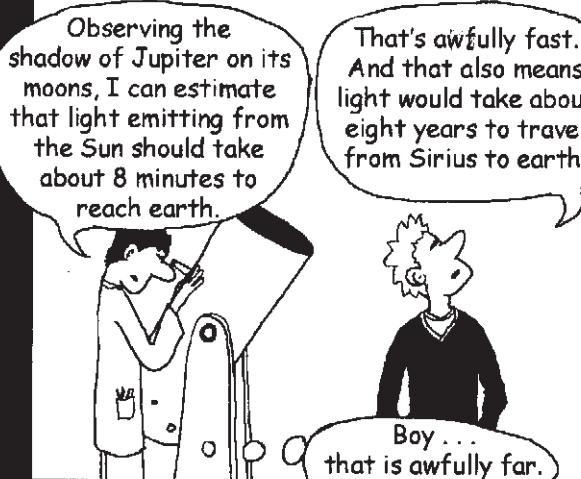
* BY BUS IN THIS CONTEXT.

COULD ONE TALK ABOUT ASTRONOMICAL DISTANCES IN TERMS OF TRAVEL TIME?

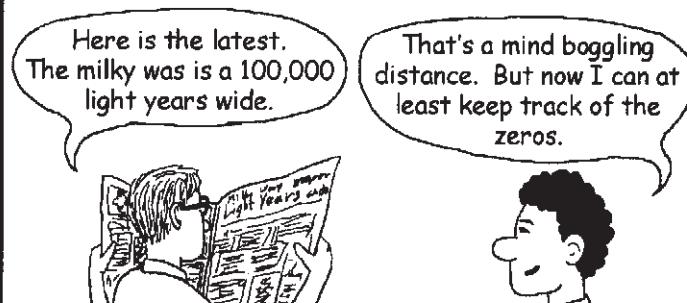


IF THERE WAS ANYTHING THAT TRAVELED ACROSS THE UNIVERSE, AND WAS FAMILIAR TO US, IT WAS LIGHT.

LIGHT MOVED WITH A TERRIFIC SPEED. SCIENTISTS DEVISED EXPERIMENTS TO FIGURE OUT HOW FAST IT TRAVELED.



THE DISTANCE COVERED BY LIGHT TRAVELING IN SPACE FOR ONE WHOLE YEAR IS CALLED A LIGHT YEAR. IT SOON BECAME A VERY CONVENIENT UNIT FOR MEASURING STELLAR DISTANCES.



LIGHT CAN GO AROUND THE EARTH 7 TIMES IN A SINGLE SECOND. CAN YOU IMAGINE HOW FAR IT CAN TRAVEL IN ONE WHOLE YEAR? IT WOULD BE ABOUT 9,000,000,000,000 KILOMETERS, OR 60,000 AU.

Stellar Parallax At Last

WHILE THE ASTRONOMERS WERE ON THE LOOK OUT FOR STELLAR PARALLAX, OTHER IMPORTANT DEVELOPMENTS TOOK PLACE.

IN 1728, JAMES BRADLEY POINTED OUT THAT . . .

... if the Earth is hurtling in space, then the light reaching us will appear to be coming at an angle slightly different than the actual. This will cause a minute distortion in the observed position of heavenly bodies.

EVER NOTICED HOW THE RAIN DROPS FALLING VERTICALLY DOWN, APPEAR TO BE COMING AT AN ANGLE, IF YOU ARE RUNNING?

My back is still dry!

A CAREFUL ANALYSIS OF PAST DATA SHOWED THAT THERE WAS INDEED A DISTORTION OF STELLAR POSITIONS INDICATING THE MOTION OF EARTH AROUND THE SUN.

Bradley is a genius. Do you know what we have here? An experimental proof that our Earth is hurtling in space.

But the bad news is, we'll have to account for this distortion and reanalyze all the data.

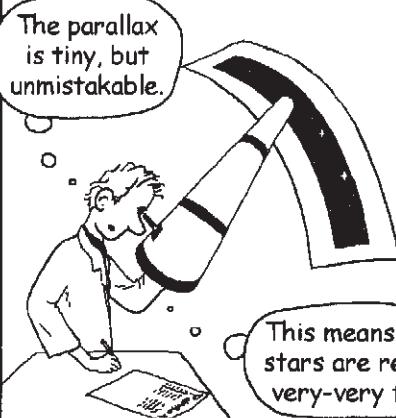
IN 1748, BRADLEY NOTICED YET ANOTHER SOURCE OF ERROR.

Earth's axis of rotation itself is turning slowly.

Don't tell me this. Now we'll have to go through another round of corrections.

Annoying as it may appear to us today, his pointing out our mistakes will only lead to progress in astronomy.

IT WAS WORTH THE WAIT, WHEN FINALLY, FRIEDRICH BESSEL, A GERMAN ASTRONOMER, DETECTED A STELLAR PARALLAX IN 1838.



BESSEL WOULDN'T HAVE BEEN ABLE TO DETECT A STELLAR PARALLAX WITHOUT THE LATEST IMPROVEMENTS IN THE TELESCOPE. AND OF COURSE HE WAS LUCKY ENOUGH TO COME ACROSS ONE OF THE VERY FEW STARS WITH A DETECTABLE PARALLAX.

SOON Hordes of Astronomers Were Detecting and Measuring Parallax in Stars.

But still, the majority of the stars show no parallax.

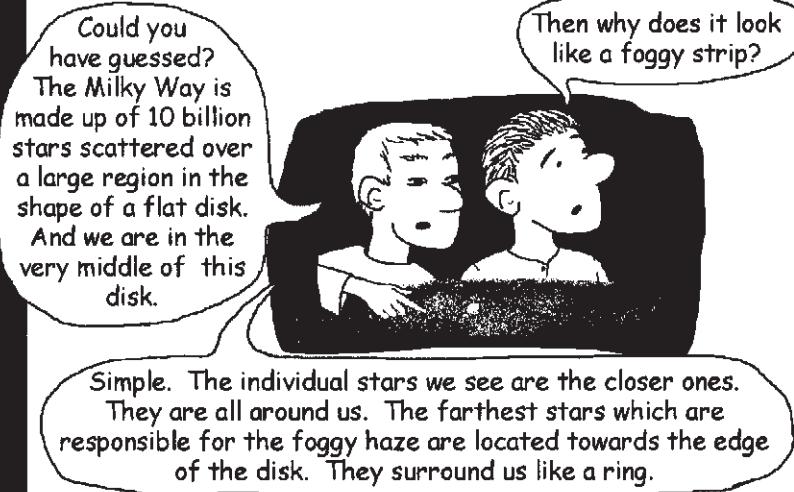
Which means only a very few of them are close to us - within a hundred thousand billion km.

You call that close?

EVEN THE NEAREST STARS ARE THOUSANDS OF TIMES FARTHER THAN THE OUTER LIMITS OF THE SOLAR SYSTEM.

The Galactic Universe

THE FIRST THING GALILEO'S TELESCOPE REVEALED WAS THAT THE SKY HELD MANY-MANY MORE STARS THAN WERE VISIBLE TO THE NAKED EYE. IN THE MID 1700S, WILLIAM HERSCHEL, AN AMATEUR ASTRONOMER, STUDIED HOW THE STARS WERE SCATTERED ACROSS THE SKY. HIS ANALYSIS TURNED OUT VERY INTERESTING.



Could you have guessed?

The Milky Way is made up of 10 billion stars scattered over a large region in the shape of a flat disk. And we are in the very middle of this disk.

Then why does it look like a foggy strip?

Simple. The individual stars we see are the closer ones.

They are all around us. The farthest stars which are responsible for the foggy haze are located towards the edge of the disk. They surround us like a ring.

THE MILKY WAY POPULARLY CAME TO BE KNOWN BY ITS GREEK NAME GALAXY.

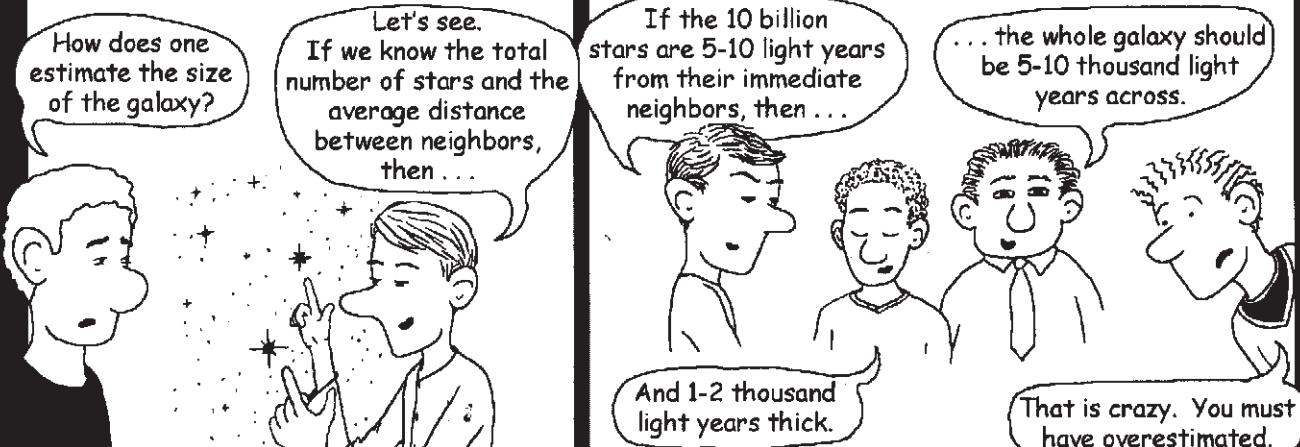
HERSCHEL HAD NO IDEA HOW LARGE THE GALAXY WAS. HE MISTAKENLY BELIEVED THE SOLAR SYSTEM TO BE IN THE MIDDLE OF THE GALAXY.

BUT THE IMPORTANT THING WAS HERSCHEL HAD FIGURED OUT THE LARGE SCALE STRUCTURE OF THE KNOWN UNIVERSE.

THE DISK SHAPED GALAXY FILLED WITH BILLIONS OF STARS WAS THE UNIVERSE, AND THE SUN WAS ONE SUCH STAR IN THE GALAXY.

THIS PICTURE OF THE UNIVERSE STAYED FOR THE NEXT 150 YEARS.

IN THE 19TH CENTURY, WHEN BESSEL SUCCEEDED IN DETECTING STELLAR PARALLAX, THE QUESTION OF THE SIZE OF THE UNIVERSE AGAIN BECAME A HOT TOPIC.



THIS ESTIMATE WAS CRUDE BUT GAVE A CONCRETE SIZE TO THE UNIVERSE.

ON THE CONTRARY, THE INITIAL ESTIMATES OF THE SIZE OF THE GALAXY WERE QUITE BELOW THE MARK. MORE POWERFUL TELESCOPES AND ADDITIONAL DISCOVERIES SHOWED THE MILKY WAY TO BE FAR LARGER THAN ASSUMED EARLIER.

ACCORDING TO CURRENT ESTIMATES, THE MILKY WAY HAS OVER 200,000,000,000 STARS SCATTERED IN THE FORM OF A HUGE DISK - 100,000 LIGHT YEARS WIDE, WITH A CENTRAL BULGE 10,000 LIGHT YEARS THICK.

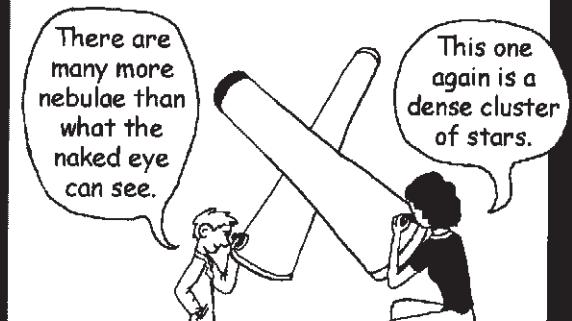
AND OUR OWN SOLAR SYSTEM IS SOMEWHERE BETWEEN THE CENTER AND THE EDGE OF THIS DISK.

Nebulae - Celestial Clouds

OTHER THAN THE PLANETS, THE MOON, THE STARS AND THE MILKY WAY, THE NIGHT SKY HAD SOME FOGGY PATCHES. THEY WERE CALLED NEBULAE (PLURAL FOR NEBULA MEANING A CLOUD IN LATIN).



NEEDLESS TO SAY, THE TELESCOPE REVEALED A LOT ABOUT NEBULAE.

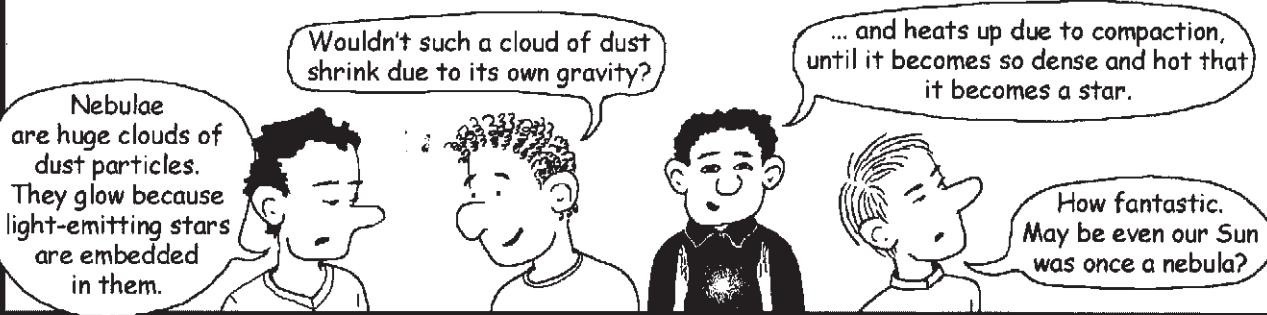


THE TRUE NEBULA LOOKED LIKE GAS HANGING AMONG THE STARS EVEN THROUGH THE BEST OF THE TELESCOPES.



THIS IS HOW SOME OF THE NEBULAE APPEAR THROUGH THE MODERN TELESCOPES.

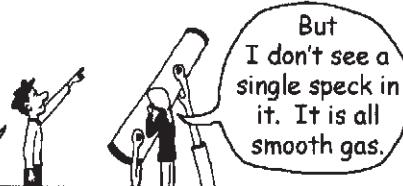
WHAT WERE THESE NEBULAE? WHAT WAS THIS FOGGY GAS DOING AMONGST STARS? NEBULAE GAVE RISE TO MANY QUESTIONS. AND THERE WERE MANY THEORIES.



THE NEBULAE SHOWED A GREAT VARIATION IN SHAPE, SIZE AND GLOW. BUT THE KIND OF LIGHT COMING FROM THESE INTERSTELLAR CLOUDS WAS VERY DIFFERENT THAN THAT FROM THE STARS.

BUT THERE WAS ONE EXCEPTION.

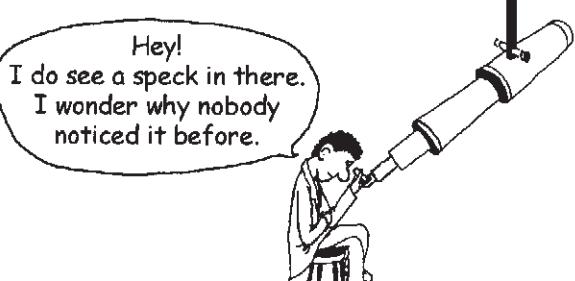
Do you see the nebula in the Andromeda constellation? I can swear all it emits is star light.



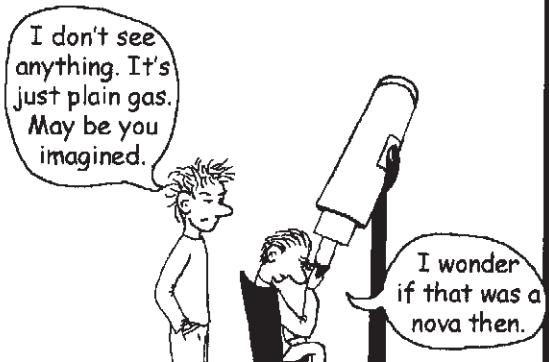
But I don't see a single speck in it. It is all smooth gas.

Andromeda Nebula

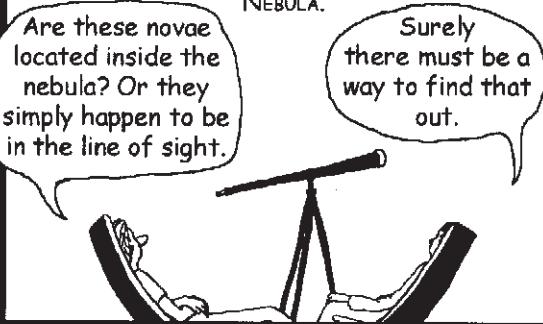
THIS NEBULA LOCATED IN THE ANDROMEDA CONSTELLATION CAME TO BE KNOWN AS THE ANDROMEDA NEBULA.



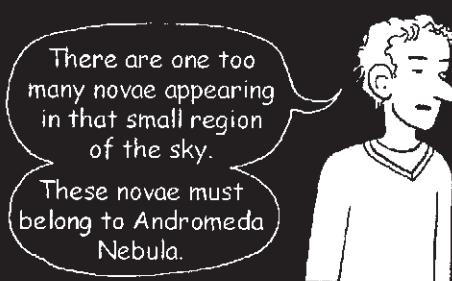
BUT THE TINY SPOT DISAPPEARED WITHIN NO TIME.



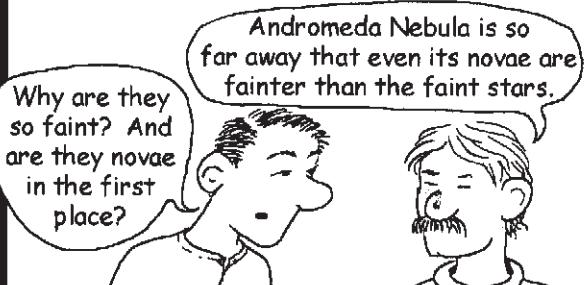
IN THE FOLLOWING DECADES, MANY TRANSIENT SPOTS WERE WITNESSED IN THE ANDROMEDA NEBULA.



HEBER CURTIS, AN AMERICAN ASTRONOMER, STUDIED THE OCCURRENCE OF NOVAE ACROSS THE WHOLE SKY AND CAME TO A CONCLUSION.



AS ALWAYS, MANY QUESTIONS WERE RAISED AND MANY THEORIES PROPOSED.



How is this possible? If what you are saying is true, then the nebulae has to be much farther than the outer limits of the universe.

If the nebula is that far, it would be impossible to figure out whether it is a cloud of dust or a dense cluster of stars.

This is all speculation. What we need is some solid proof.

IN 1917, EDWIN HUBBLE, AN AMERICAN ASTRONOMER, RESOLVED THE ANDROMEDA NEBULA INTO A VAST BUT DENSE COLLECTION OF EXTREMELY FAINT STARS.

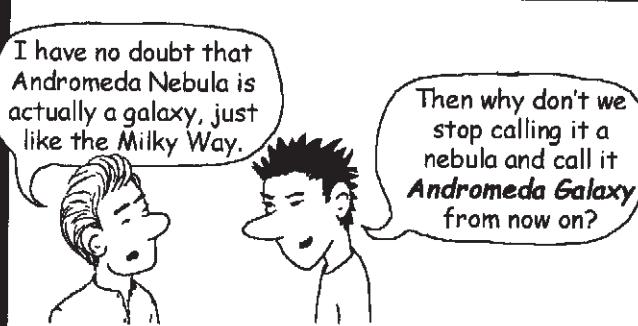


THE THEORY THAT THE ANDROMEDA NEBULA WAS A SEPARATE AND DISTANT GALAXY FITTED MOST OBSERVATIONS.

Yet again the universe turned out to be much more complex than we thought.

And much larger than we could have imagined.

Multigalactic Universe



USING SOPHISTICATED INSTRUMENTS AS WELL AS METHODOLOGY, SCIENTISTS ESTABLISHED THAT ANDROMEDA NEBULA WAS INDEED A GALAXY LIKE THE MILKY WAY, ONLY TWICE AS WIDE.

IT HAS BEEN CALLED ANDROMEDA GALAXY FROM THEN ON.

IN 1952 THE ANDROMEDA GALAXY WAS ESTIMATED TO BE AN ASTONISHING 2 MILLION LIGHT YEARS AWAY FROM US.



WAS THAT ALL THERE WAS TO THE UNIVERSE?
TWO GALAXIES SEPARATED BY A MIND BLOWING DISTANCE?
THE ASTRONOMERS SEEMED TO KNOW BETTER.

IT CAME AS NO BIG SURPRISE WHEN MANY MORE GALAXIES WERE DISCOVERED SOON AFTER.



SO WHAT IS OUR CURRENT PICTURE OF THE UNIVERSE?

The universe is scattered with galaxies . . . around 100,000,000,000 (a hundred billion) of them grouped into clusters. Each galaxy cluster is made up of thousands of galaxies.

The average sized galaxy has 100,000,000,000 (hundred billion) stars and is 100,000 light years across.

The expanse of the universe is estimated to be around 200,000,000,000 (two hundred billion) light years.

There is a vast space separating stars in a galaxy as well as galaxies in a cluster. In fact, the universe is mostly vast, empty space. Well . . . this space is not really empty . . . because there is a faint light flooding every corner of the universe.

THAT IS CRAZILY BIG. BUT IS THAT ALL THERE IS TO THE UNIVERSE? YES . . . FOR NOW.

But who knows? May be one day, we will discover something new, somewhere beyond the known boundaries of this Multi-galactic Universe.

The Universe in Chunks

WHERE ARE WE LOCATED WITHIN THE ENORMOUS UNIVERSE WE LIVE IN? WHERE DO OUR EARTH, OUR SOLAR SYSTEM, OUR MILKY WAY LIE IN RELATION TO THE BILLIONS AND BILLIONS OF GALAXIES MAKING UP THE COSMOS?

The night sky we see is dominated by the stars neighboring us. I would like to travel far away from all the stars and all the galaxies and take a perspective look at the universe.

SUPPOSE WE HAD THE ABILITY TO TRAVEL TO ANY PLACE IN THE UNIVERSE. YOU MOVE AWAY AS FAR FROM THE EARTH AS POSSIBLE. WHAT WOULD YOU SEE? A SWARM OF FAINT DOTS. ARE THESE STARS? GALAXIES?



No. EACH TINY DOT IS A CLUSTER OF GALAXIES. AN AVERAGE SIZED CLUSTER CONTAINS MORE THAN A THOUSAND GALAXIES. THERE ARE MORE THAN A BILLION SUCH CLUSTERS SCATTERED ACROSS A VAST SPACE.

1,000,000,000

light years

LET US START LOCATING THE EARTH. SUPPOSE WE TAKE A SMALL CHUNK FROM THIS VIEW ALONG THE DIRECTION WE CAME FROM. IF WE ZOOM INTO THIS PIECE, WE CAN MAKE OUT THE INDIVIDUAL GALAXIES IN THE CLUSTERS.

Surely one of these galaxies is our Milky Way?

10,000,000

light years

INDEED. LET US ZOOM FURTHER INTO A TINY PIECE OF THIS SPACE NEIGHBORING OUR GALAXY.

Ah! This looks like the Milky Way. And the other galaxy over there has to be Andromeda.

100,000

light years

IT IS TIME TO LOOK FOR OUR SUN. AGAIN WE ZOOM INTO A SMALL REGION OF THE MILKY WAY IN THE DIRECTION OF THE SOLAR SYSTEM.

Not good enough. All I see is a crowd of stars. We need to zoom further in.

1000

light years

WE TAKE ANOTHER STEP TOWARDS OUR DESTINATION. NOW WE CAN DISTINCTLY SEE INDIVIDUAL STARS.

At last! ... the Sun. The star next to it is Proxima Centauri.

10 light years

600,000 AU

THAT HAS BEEN QUITE A JOURNEY SO FAR. BUT WE HAVE A LONG WAY TO GO BEFORE WE REACH HOME.

Back Home

ZOOMING ONCE MORE, OUR FIELD OF VISION IS NARROWED TO ONLY ONE STAR, THE SUN.

0.1 light years

6,000 AU

Are you sure that is our Sun?
I don't see any planets orbiting it.

TO SEE THE STRUCTURE OF THE SOLAR SYSTEM,
WE NEED TO STEP MUCH CLOSER.

1 AU

Now I see some dots.
Must be the outer planets.

IT IS ABOUT TIME WE STARTED LOOKING
FOR THE PLANET WE CALL HOME. LET US
PLUNGE RIGHT INTO THE SOLAR SYSTEM.

0.6 AU
100,000,000 km

That one looks like Saturn and the
other one is Jupiter. That tiny one
must be Mars ... EARTH!

NOW THAT THE EARTH HAS BEEN LOCATED,
THE REST OF THE JOURNEY IS TRIVIAL.

1,000,000 km

We have zoomed in quite a bit now. Yet the
Earth appears no larger than a dot. Could
you have imagined we live on such a tiny ball
floating in space?

WE ARE ALMOST THERE.
ZOOM IN ONE LAST TIME
AND IT IS TIME TO ...

10,000 km

Prepare for
LANDING!



Space And Time

THE LIGHT YEAR HAS CEASED TO BE THE NATURAL UNIT IT ONCE USED TO BE.

They say the universe is 10,000,000,000 light years wide.

You mean 10^{10} light years. That would be 10^{26} meters.

YET,
THE LIGHT
YEAR PLAYS A
SPECIAL ROLE
IN
PICTURING
THE
UNIVERSE.

A DISTANCE EXPRESSED IN LIGHT YEARS EXPLICITLY TELLS THE TIME IT TAKES LIGHT TO COVER THAT DISTANCE.

So what I see today is what the Andromeda Galaxy looked like 2,000,000 years ago?

Correct. That's how long light takes to reach us from Andromeda.

If this is how it looked 2,000,000 years ago, what does it look like now?

Probably not any different. A galaxy doesn't change much in a few million years. But there is no way of knowing for sure.

THE DEEPER WE LOOK INTO SPACE, THE FARTHER BACK WE DIG IN TIME.

These are the distant most objects in the universe.

Then they must also be the most ancient.

THESE MOST DISTANT OBJECTS, NAMED QUASARS, ARE PROBABLY YOUNG GALAXIES OF A NEW BORN UNIVERSE. BECAUSE OF THEIR VAST DISTANCE, WE DON'T REALLY KNOW THEIR SHAPE.

ACCORDING TO OUR CURRENT UNDERSTANDING THE MOST DISTANT QUASARS MARK THE BEGINNING OF THE UNIVERSE. IF WE SEE NOTHING BEYOND THEM, IT IS PROBABLY BECAUSE NOTHING EXISTED BEFORE THEM.

One thing is for sure. These quasars actually look very much different than how they appear through the telescope.

And they would be in a different location too. What we're seeing now is a billion-year-old movie!

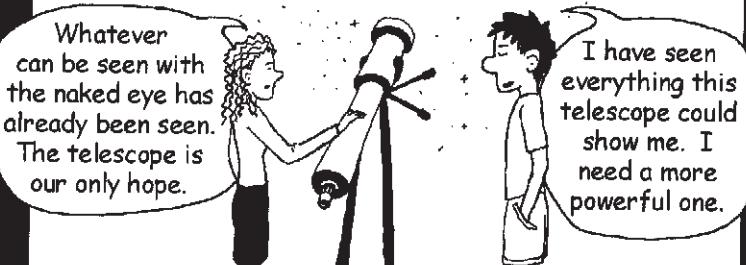
Makes sense doesn't it?

But who knows. May be one day . . .

INDEED, IF THE STORY OF ASTRONOMY HAS TAUGHT US ANYTHING . . . NO THEORY IS FINAL.

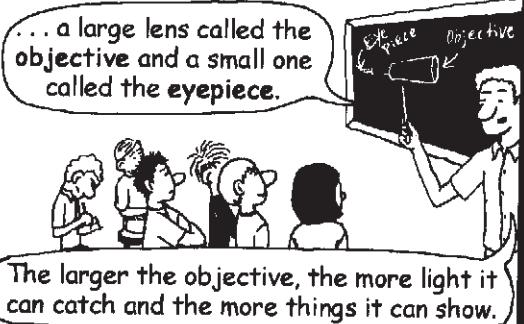
Evolution Of Telescopes

EVER SINCE GALILEO USED THE TELESCOPE 400 YEARS AGO THIS INSTRUMENT HAS BEEN INSEPARABLY LINKED TO ASTRONOMY.



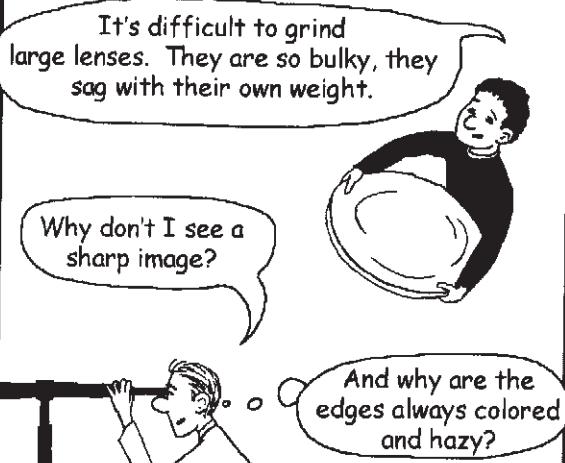
ADVANCEMENT IN OBSERVATIONAL ASTRONOMY ESSENTIALLY MEANT IMPROVEMENT IN THE TELESCOPE.

THE FIRST TELESCOPES (CALLED GALILEAN TELESCOPES) CONSISTED OF TWO LENSES.

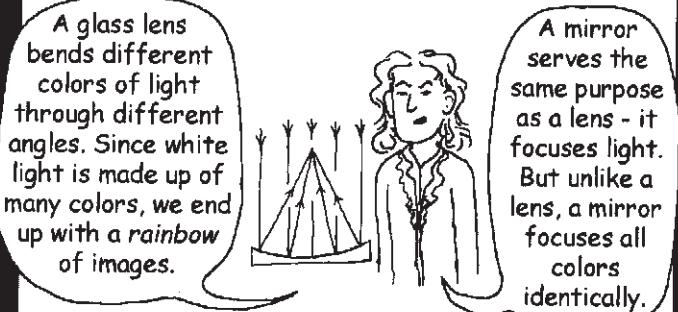


IN 1700 WILLIAM HERSCHEL CONSTRUCTED A 40 FEET LONG TELESCOPE. ITS OBJECTIVE HAD A DIAMETER OF 4 FEET.

THE GALILEAN TELESCOPE HAD SOME INHERENT PROBLEMS.



NEWTON'S DEEP INSIGHT INTO THE NATURE OF LIGHT MADE HIM REPLACE THE OBJECTIVE LENS WITH A CURVED MIRROR.



MOREOVER, THE MIRROR HAD ONLY ONE SURFACE TO BE GROUND AND WAS MUCH LIGHTER COMPARED TO A LENS. THE REFLECTING TELESCOPE (ALSO KNOWN AS THE NEWTONIAN TELESCOPE) STILL REMAINS THE DARLING OF AMATEUR ASTRONOMERS.

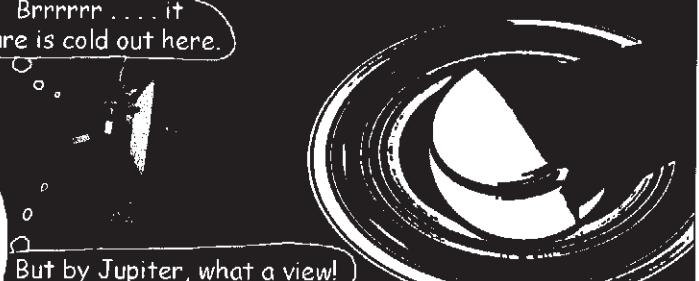
CONSTRUCTING BETTER TELESCOPES WAS ONLY ONE OF THE CHALLENGES. ASTRONOMERS HAD TO GRAPPLE WITH DUST AND FLUCTUATIONS IN THE ATMOSPHERE WHICH LIMITED THE OBSERVATIONAL POWER OF TELESCOPES.



TODAY, MOST OF THE OBSERVATORIES ARE RECLUSIVE RETREATS SITUATED ON MOUNTAIN TOPS.

THESE DAYS THE CLEAREST PICTURES OF THE COSMOS ARE OBTAINED THROUGH TELESCOPES PLANTED IN SPACE.

Brrrrrrr it sure is cold out here.

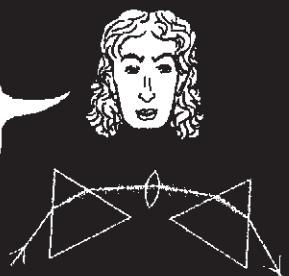


SOME TELESCOPES ORBIT THE EARTH WHILE OTHERS HAVE TRAVELED ACROSS THE SOLAR SYSTEM. WELL KNOWN SPACE TELESCOPES LIKE HUBBLE AND VOYAGER HAVE SENT US INNUMERABLE PICTURES OF THE UNIVERSE - INFORMATIVE AS WELL AS BREATHTAKINGLY BEAUTIFUL.

Spectrum

AS THE TELESCOPES ADVANCED TO REVEAL THE SKY IN GREATER AND GREATER DETAIL, AN EQUALLY POWERFUL DEVELOPMENT TOOK PLACE.

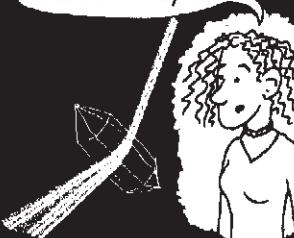
Look!
Sunlight is made
up of several
colors. The prism
splits the beam
into its colored
components.



And if you
recombine
these
components,
you again get
the white
light you
started
with.

THE ANCIENTS
KNEW THAT LIGHT
PASSING THROUGH
CRYSTALS YIELDED
A RAINBOW-LIKE
PATTERN. BUT
THEY THOUGHT IT
WAS THE CRYSTAL
WHICH RENDERED
THE COLORS.

After all
crystals are magical
aren't they?



THIS DISCOVERY BY NEWTON IN 1666 HAD PROFOUND IMPLICATIONS.

BUT AFTER NEWTON'S EXPLANATION, THE
FOCUS SHIFTED FROM CRYSTALS TO LIGHT.

DURING THE 18TH CENTURY PEOPLE DISCOVERED THAT LIGHT CONTAINED MUCH MORE THAN A RAINBOW OF COLORS.

SCIENTISTS CONDUCTED EXPERIMENTS IN THE DARK ROOM.

That is strange! Even the dark
regions next to the rainbow have a
warming effect.

Hey, this is spooky!
The photograph of the rainbow
is much wider than the rainbow
itself.

I know what this means.
The sunlight has some colors
which are invisible to the human
eye. The prism separates them
just like it does the visible
colors.

THE RANGE OF COLORS, INCLUDING THE INVISIBLE ONES
WAS CALLED THE SPECTRUM.

I name this
invisible region of the
spectrum beyond violet
THE ULTRAVIOLET.

Well, let's call the
other invisible region,
the one before red,
THE INFRARED.

ACCORDING TO MODERN THEORY, LIGHT IS MADE UP OF WAVES. LIGHT OF DIFFERENT COLORS HAVE DIFFERENT WAVELENGTHS. WITHIN THE VISIBLE SPECTRUM (THE RAINBOW COLORS), RED HAS THE LONGEST WAVELENGTH AND VIOLET HAS THE SHORTEST. ULTRAVIOLET LIGHT HAS AN EVEN SHORTER WAVELENGTH. INFRARED CORRESPONDS TO A WAVELENGTH LONGER THAN THAT OF RED.

TODAY WE KNOW THAT THE FULL SPECTRUM OF LIGHT IN THE UNIVERSE EXTENDS MUCH BEYOND THE INFRARED AND THE ULTRAVIOLET. VISIBLE LIGHT IS JUST A TINY PORTION OF THIS.

JUST LIKE THE COLORS OF THE RAINBOW, DIFFERENT PARTS OF THE INVISIBLE SPECTRUM ARE ALSO GIVEN NAMES; X-RAYS, GAMMA RAYS, MICRO WAVES, RADIO WAVES, ETC.

Spectroscopy

IN 1835, AUGUSTE COMTE, A FRENCH PHILOSOPHER SAID . . .

Humans would NEVER be able to tell what the STARS are made of!



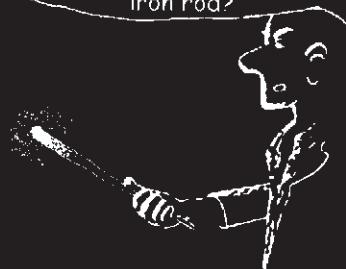
HE WAS TO BE PROVED WRONG VERY SOON.

IN THE 19TH CENTURY, A SERIES OF INVESTIGATIONS BROUGHT THE STUDY OF THE LIGHT SPECTRUM INTO THE HEART OF ASTRONOMY.

If I pass the light from this candle through a prism, what would the resulting rainbow look like?

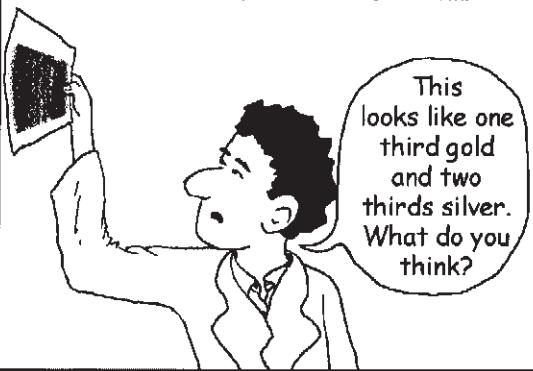


How about the light coming from this white-hot iron rod?



LIGHT EMITTING FROM DIFFERENT SOURCES WAS INVESTIGATED.

MUCH TO THEIR EXCITEMENT, SCIENTISTS FOUND THAT DIFFERENT MATERIALS, WHEN HEATED, GAVE OUT DIFFERENT SPECTRA. AFTER MUCH STUDY, THEY WERE ABLE TO IDENTIFY THE SUBSTANCES EMITTING LIGHT JUST BY LOOKING AT THE SPECTRUM.



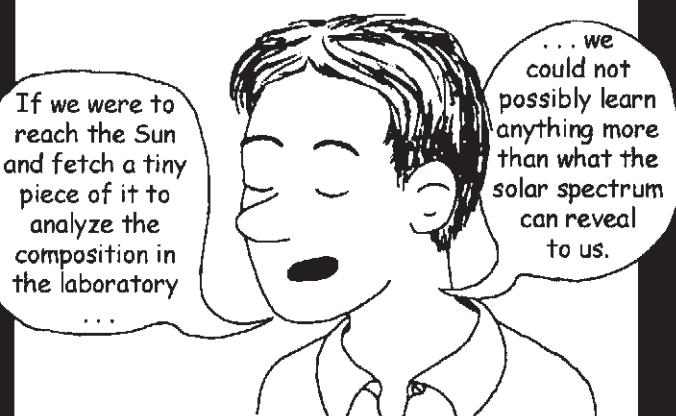
This looks like one third gold and two thirds silver. What do you think?

ASTRONOMERS WERE THRILLED WITH THIS NEW ABILITY.

This is really exciting! Why don't we look at the spectra of stars? May be we can tell what elements are responsible for their glow.



SOON THIS EXCITEMENT GOT CONVERTED INTO A DEEP FAITH.



If we were to reach the Sun and fetch a tiny piece of it to analyze the composition in the laboratory . . .

. . . we could not possibly learn anything more than what the solar spectrum can reveal to us.

THE ELEMENT HELIUM (USED IN FLOATING BALLOONS) WAS FIRST IDENTIFIED THROUGH THE SOLAR SPECTRUM. LATER ON IT WAS ISOLATED IN THE LABORATORY.

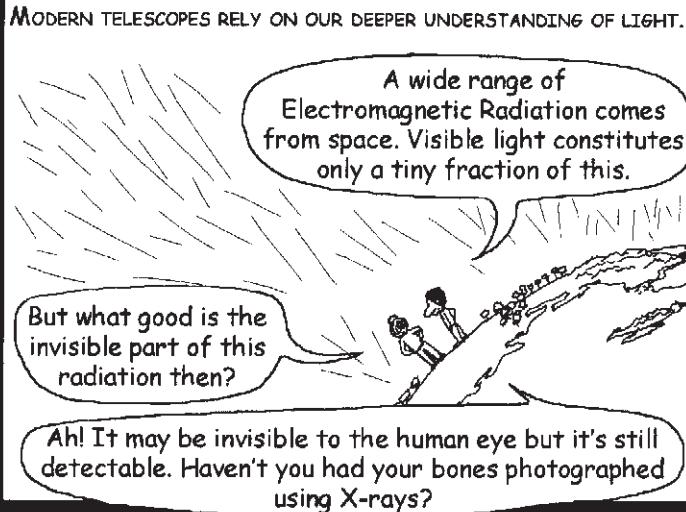
SPECTRA FROM PLANETS, STARS, NEBULAE, GALAXIES, ETC. WERE ANALYZED IN DETAIL. THIS LEAD TO THEORIES WHICH TALKED ABOUT WHAT CONSTITUTED STARS AND NEBULAE AND HOW THAT MATTER BURNED TO PRODUCE LIGHT.

SPECTROSCOPY SHIFTED THE FOCUS FROM THE GEOMETRICAL STRUCTURE OF THE UNIVERSE TO THE PHYSICAL PROCESSES HAPPENING THERE.

NEWTON HAD ESTABLISHED THE PHYSICS OF HOW HEAVENLY BODIES MOVED IN SPACE AND HOW THEY INTERACTED WITH ONE ANOTHER. SPECTROSCOPY MADE IT POSSIBLE TO STUDY THE PHYSICAL PROCESSES OCCURRING WITHIN EACH CELESTIAL OBJECT.

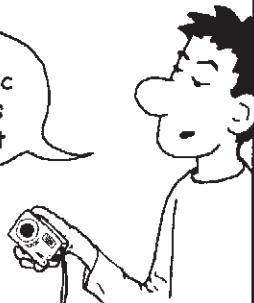
TODAY ASTRONOMY IS CONSIDERED A BRANCH OF PHYSICS.

Modern Telescopes



INVISIBLE LIGHT CAN BE PHOTOGRAPHED ON FILM. ADVANCE ELECTRONICS HAVE GIVEN US ARTIFICIAL RETINAS WHICH SEE MUCH MORE THAN THE HUMAN EYE CAN.

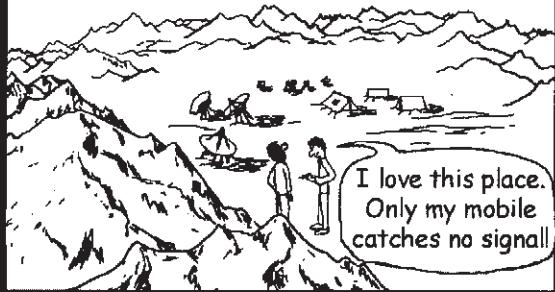
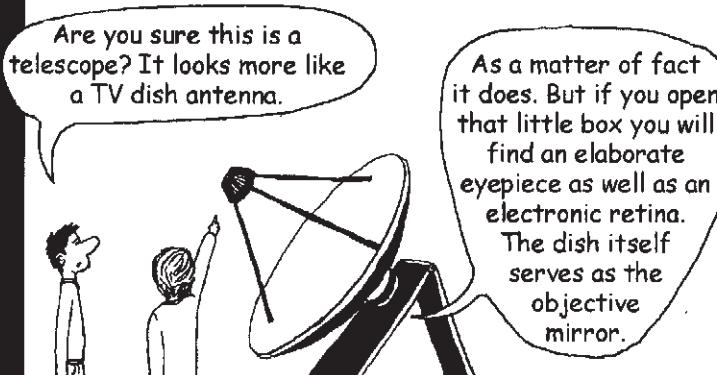
A digital camera for example uses an electronic retina. Electronic retinas can capture invisible light too.



TELESCOPES MEANT FOR INVISIBLE LIGHT ARE USUALLY THE REFLECTING (NEWTONIAN) TYPE.

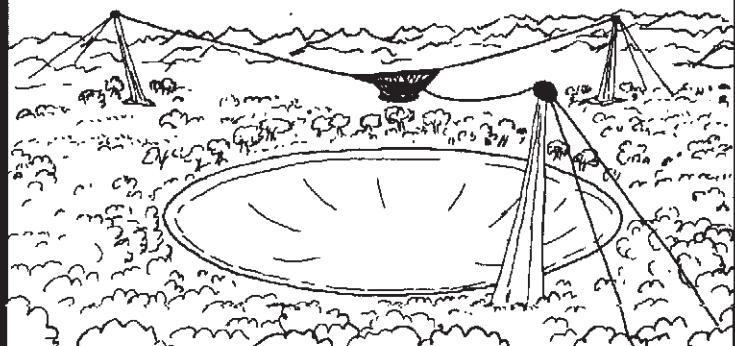
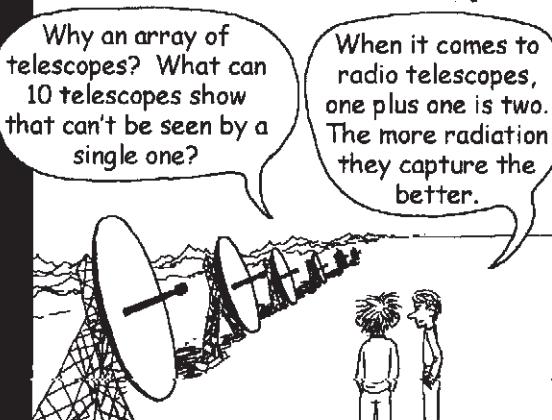
MOST MODERN TELESCOPES CAPTURE INVISIBLE LIGHT. DEPENDING ON THE REGION OF THE SPECTRUM THEY ARE SENSITIVE TO, THEY ARE NAMED INFRARED TELESCOPES, X-RAY TELESCOPES, RADIO TELESCOPES, ETC.

AS MOUNTAIN TOPS ARE GOOD FOR VISIBLE-LIGHT TELESCOPES, RADIO TELESCOPES ARE BEST LOCATED IN VALLEYS. THE SURROUNDING MOUNTAINS SHIELD UNWANTED RADIATION FROM ARTIFICIAL SOURCES.



OFTEN THERE ARE GROUPS AND ARRAYS OF RADIO TELESCOPES COLLECTIVELY IMAGING THE SKY.

THE LARGEST SINGLE-DISH TELESCOPE TODAY IS SITUATED AT ARECIBO, PUERTO RICO. THE DISH IS A FIXED 305 METERS WIDE CEMENT BOWL AND THE EYEPiece HANGS FROM CABLES.



Space Exploration

WE BELIEVE WE HAVE SEEN THE FARTHEST AND THE ANCIENT MOST OBJECTS OF OUR UNIVERSE. ASSUMING THAT OUR BELIEF IS TRUE, IS THERE ANYTHING LEFT TO BE EXPLORED?

You bet there is. Even our closest neighbor is hardly explored.



INDEED, THERE ARE INFINITE THINGS YET TO BE EXPLORED. THE CURRENT SPACE PROGRAM HAS SEVERAL AGENDAS.

The first and the foremost is to satisfy our curiosity. To know what all is out there.



Additionally we have several practical goals too.

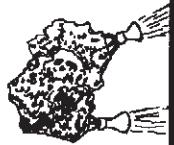


ONE MAJOR AGENDA IS TO PROTECT LIFE ON EARTH FROM GETTING OBLITERATED.

There is a faint chance that a huge meteorite may someday hit earth. This may wipe out all life on earth.



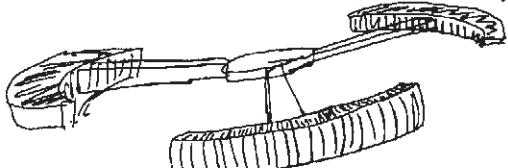
We should be able to detect such an event well in advance and divert the course of such a meteorite.



WE ARE LIKELY TO MAKE OUR PLANET UNLIVABLE. SOME THINK THAT THE ONLY WAY THE HUMAN RACE CAN SURVIVE ITSELF IS TO COLONIZE SPACE.



Just in time too!



IT WOULD BE NAIVE AND ARROGANT TO THINK THAT LIFE EXISTS ONLY ON EARTH. BUT WE MAY NEED TO TRAVEL FAR TO ENCOUNTER ALIEN LIFE.

... We have made contact!
... repeat ... we have made contact ... over.

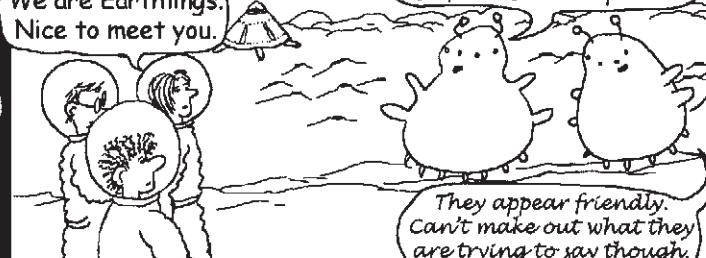


... zgrooftah#...
morei ... zgrooftah
... finnn!

DEEP SPACE TRAVEL, MEETING OTHER LIFE FORMS AND LEARNING MORE ABOUT THE UNIVERSE WILL CERTAINLY WIDEN OUR HORIZON. MAYBE IT WILL EVEN HELP US IN CONQUERING OUR PREJUDICES, PETTINESS AND GREED AND CONSIDER OURSELVES AS ONE EARTH, ONE PEOPLE.

We are Earthlings.
Nice to meet you.

Reg, you were right! There is life outside our planet.



They appear friendly.
Can't make out what they are trying to say though.